Future HE ground-based experiments: from γ-Ray Astronomy to Cosmic Rays

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Ricap 2014 - Roma International Conference on Astroparticle Physics
Noto, 30 Sept - 3 Oct 2014

Cosmic Ray Experiments & Cosmic Ray Physics

CR Experiments 10^{12} ➜ 10^{18} eV:

- ARGO-YBJ
- HAWC
- TIBET ASγ
- GRAPES
- KASCADE
- KASCADE-Grande
- Tunka-133
- IceTop

Future:

- LHAASO
- HiSCORE
- TIBET ASγ enhancements

Not discussing: Highest Energy Cosmic Rays (Auger, TA/TALE, Yakutsk, JEM-EUSO)

- The *'Scientific Case'* for new generation Extensive Air Shower (EAS) arrays in the 10^{12} - 10^{18} eV energy range

➜ open problems in Galactic Cosmic Ray Physics

Questions to the knee energy range

Cosmic Ray sources (*'PeVatrons'*)	→	**Still open**
NO smoking guns from TeV gamma-ray astronomy !		
Composition at the knee ? **Rigidity – dependent knee ?**	→	**Still open**
Results still conflicting in the knee energy region !		
Anisotropy ?	→	**Totally open**
No theory of CRs exists yet to explain observed anisotropy !		
End of Galactic spectrum ? **Transition galactic - xgalactic ?**	→	**Open**
Only hyphotheses		
Hadronic interaction models ?	→	**Still uncertain**
cross sections, diffractive, inelasticity, …		

The ‘*Cosmic Ray connection*'

★ Hadronic emission (CR sources): $p + p/\gamma \Rightarrow n \; (\pi^{+} + \pi^{-} + \pi^{0}) + h$

γ **Gamma-Ray Astronomy**

ν **Neutrino Astronomy**

CRs, photons and neutrinos strongly correlated: the ‘*cosmic ray connection*'

ONLY charged CRs observed at E > 10^{14} eV so far !

Recent observations of PeV neutrinos by Icecube

★ Leptonic emission (Inverse Compton): $e + \gamma \Rightarrow e' + \gamma'$

scattering of electrons on low energy photons:

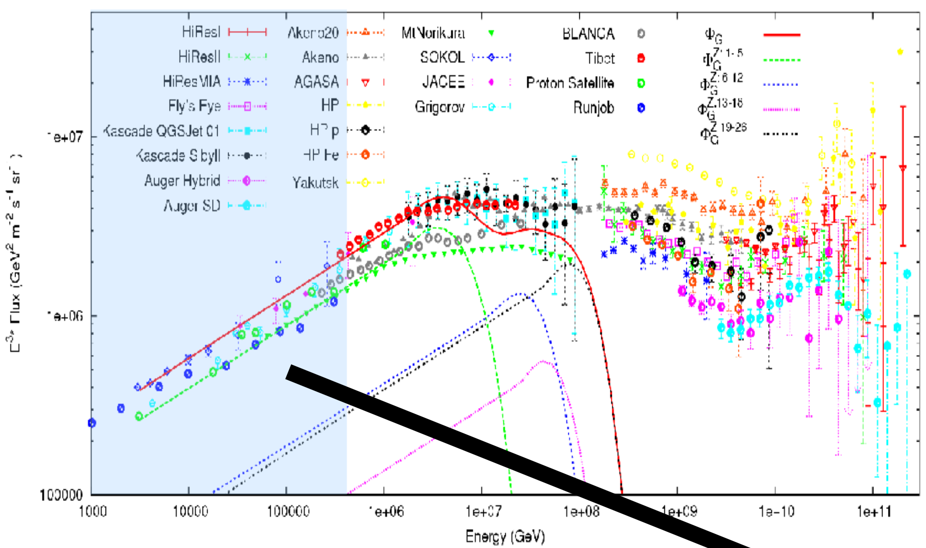
- ✓ Cosmic Microwave Background (CMB)
- ✓ Infrared, optical photons
- ✓ Synchrotron photons

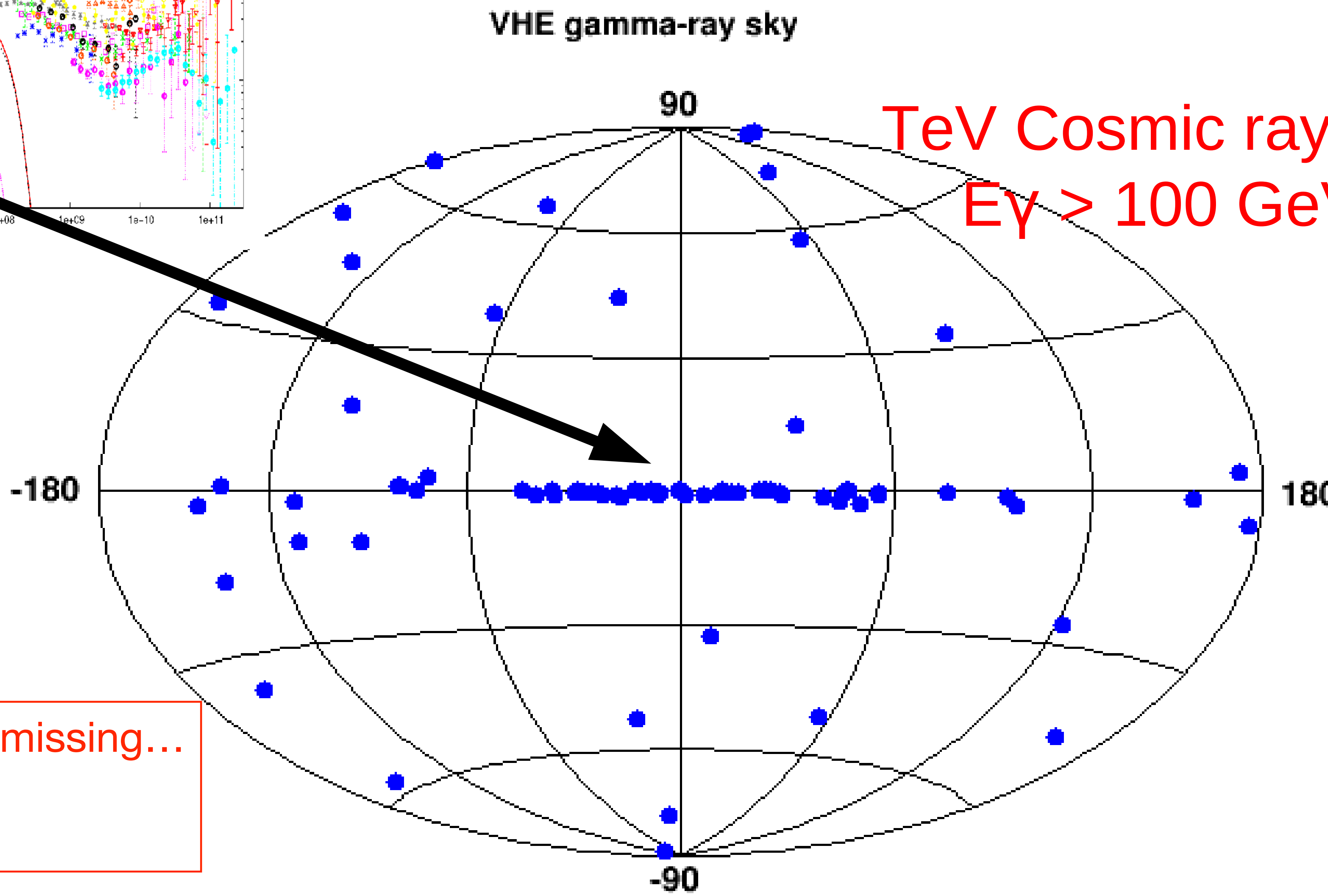
SSC model: photons radiated by high energy (10^{15} eV) electrons boosted by the same electrons

Gammas (and neutrinos) point back to their sources (SNR, PWN, BS, AGN ..)

TeVatrons sky

Gammas from Galactic Cosmic rays: $E_\gamma \sim E_{CR}/10$





TeV Cosmic rays

Eγ > 100 GeV

But smoking gun still missing…
leptonic ?
hadronic ?

Things are not simple…

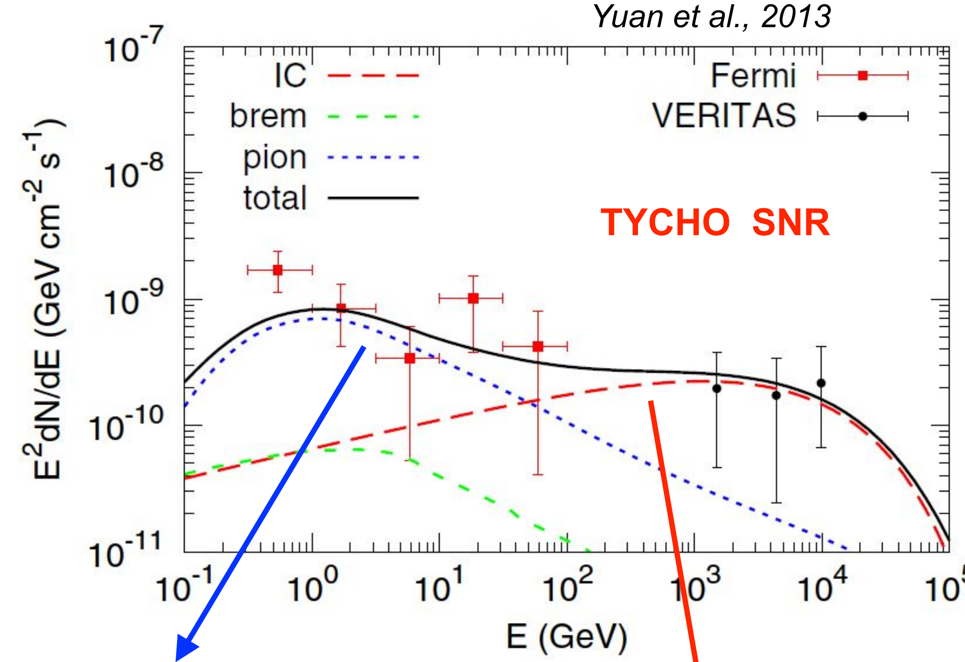
Each SNR is individual and has a unique behaviour
In general one expects a combination of leptonic and hadronic emission

The relative contributions depend on:

- Ratio of the injected electrons and protons
- Electrons and protons spectra (Power law ? Breaks ? Cutoff ?)
- Particle confinement, escape time
- Density of target material for proton interactions
- Density of low energy seed photons for electron IC
- Magnetic field strength (synchrotron emission)
- SN type
- SNR age and morphology
- Presence of Molecular Clouds
- Absorption of gamma rays
- ……

Multi-wavelenght observations are very important !

Yuan et al., 2013



Hadronic emission
π^0 decay

Leptonic emission
Electron Inverse Compton with a cutoff in the electron spectrum

BUT, in this complex scenario, one thing is clear:

★ A power law spectrum reaching 100 TeV without a cutoff is a very strong indication of the hadronic origin of the emission

Photons of few hundreds of TeV are a clear signature of acceleration of 10^{15} eV protons

Data above 30 TeV are very important…

…to discriminate between Leptonic/Hadronic emission of photons

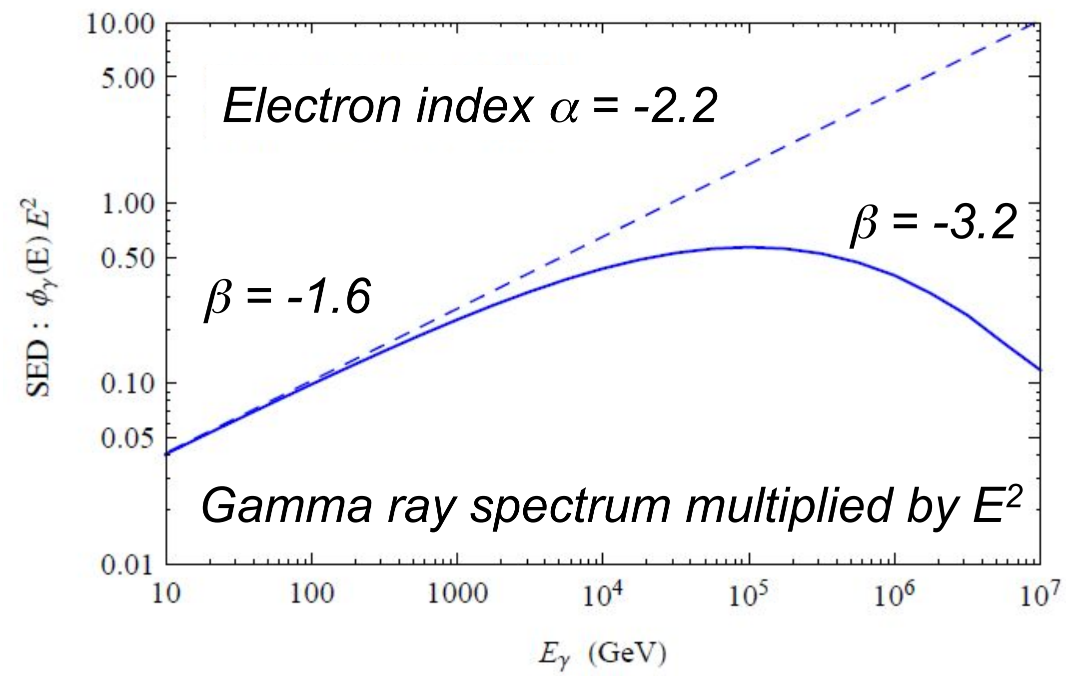
✦ *Leptonic emission:*

1) Thomson regime

$E_e\ \varepsilon \ll 4\ m_e^2$ (ε = seed photon energy)
Costant cross section: Thomson cross section)
Electron spectrum $E^{-\alpha}$
➡ Gamma ray spectrum $E^{-\beta}$, $\beta=(\alpha+1)/2$

2) Klein-Nishina regime

The cross section decreases
Photon index $\beta=\alpha+1$
In case of CMB seed photons, the KN regime starts below 100 TeV



Inverse Compton is suppressed by the Klein-Nishina effect

✦ *Hadronic emission:*

π^0 decay from proton/nuclei interactions with the ambient nuclei

There is no suppression at high energy as IC, unless the parent proton spectrum has a cutoff

Data above 30 TeV are very important…

…to discriminate between Leptonic/Hadronic emission of photons

✦ *Leptonic emission:*

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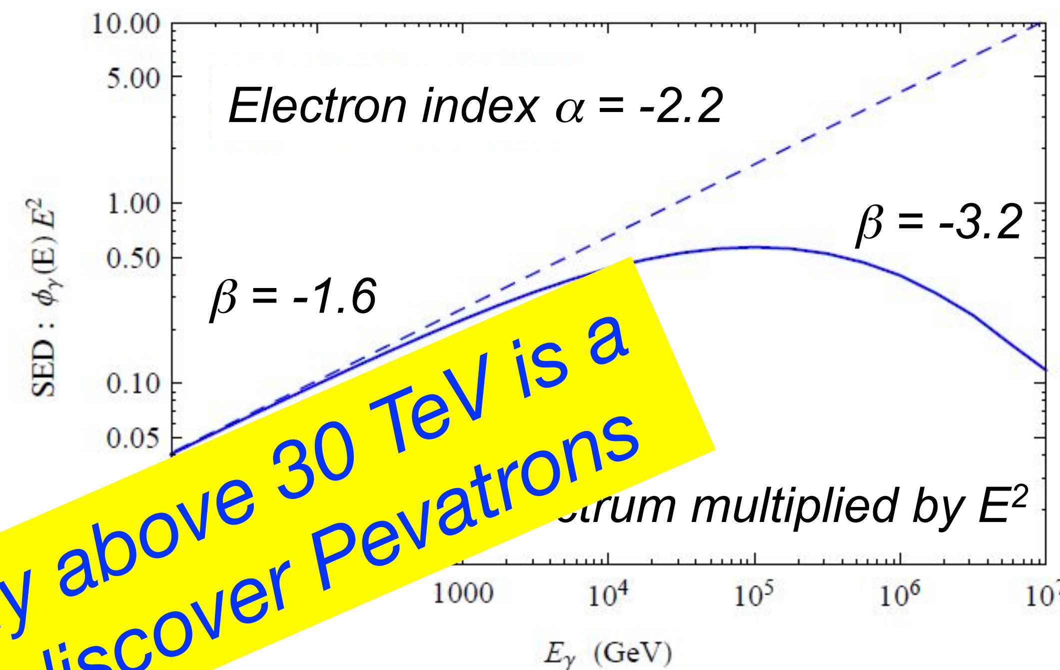


2) Klein-Nishina regime

The cross section decreases
Photon index $\beta=\alpha+1$
In case of CMB seed photons, the KN…
regime starts below 100 TeV

…e Compton is suppressed by the Klein-Nishina effect

Gamma ray astronomy above 30 TeV is a fundamental tool to discover Pevatrons

✦ *Hadronic emissio…*

π^0 decay from proton/nuclei interactions with the ambient nuclei

There is no suppression at high energy as IC, unless the parent proton spectrum has a cutoff

Gamma-Ray Astronomy above 30 TeV

Status of the art

~ 150 sources observed above 1 TeV

< 10 sources observed above 30 TeV:

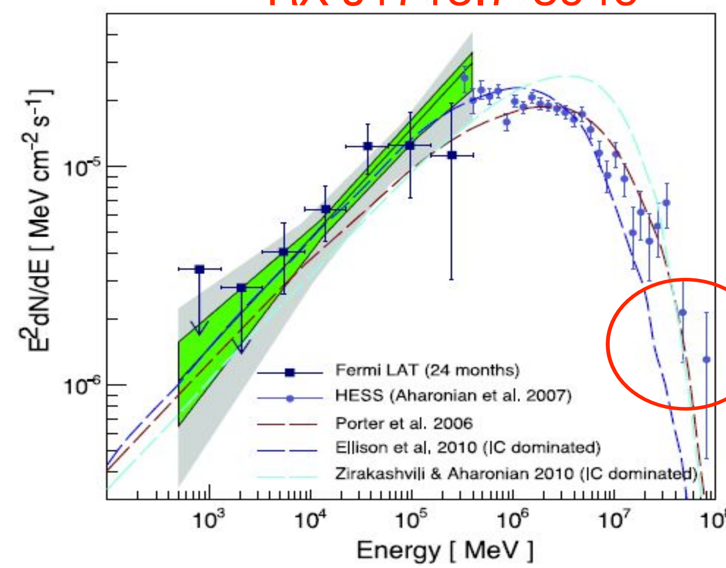
- *Crab Nebula*
- *VELA -X*
- *MGRO J2031+41*
- *MGRO J2019+37*
- *MGRO J1908+06*
- *SNR RX J1713.7-3946*

....

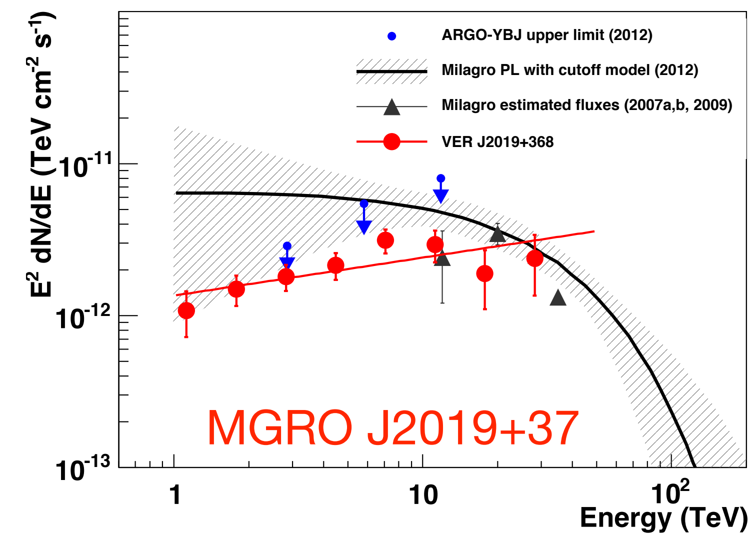
Data above 30 TeV are very scarce

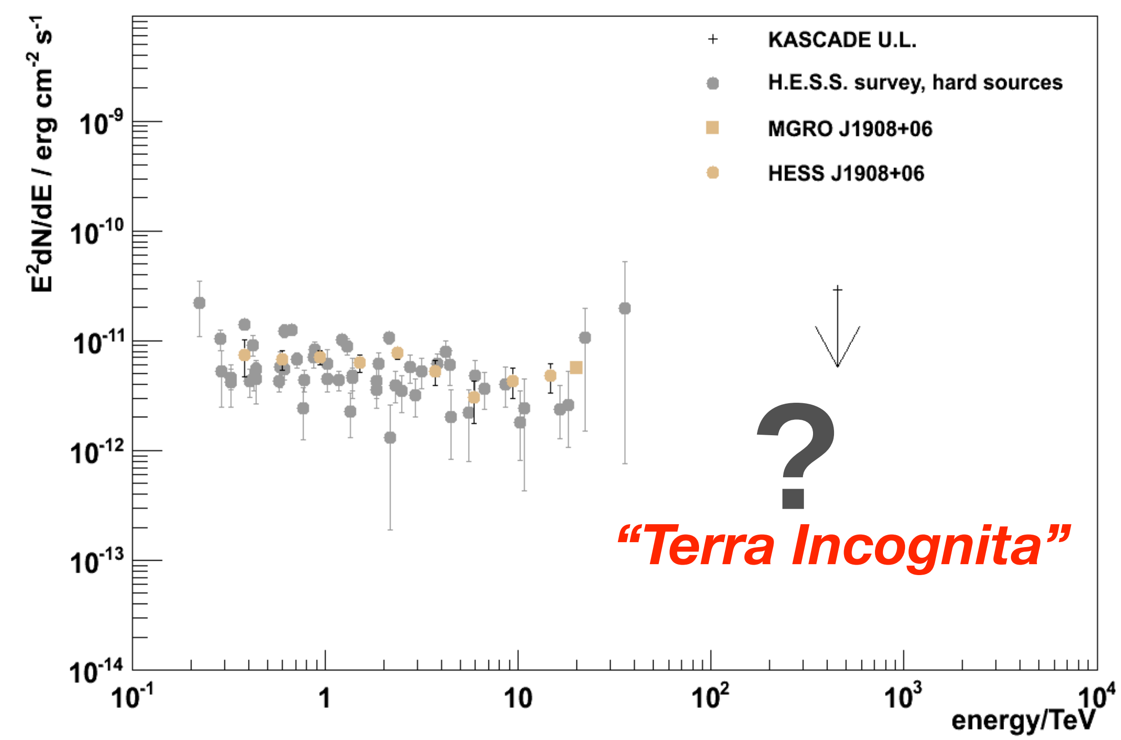
No photons detected above 100 TeV !

RX J1713.7-3946



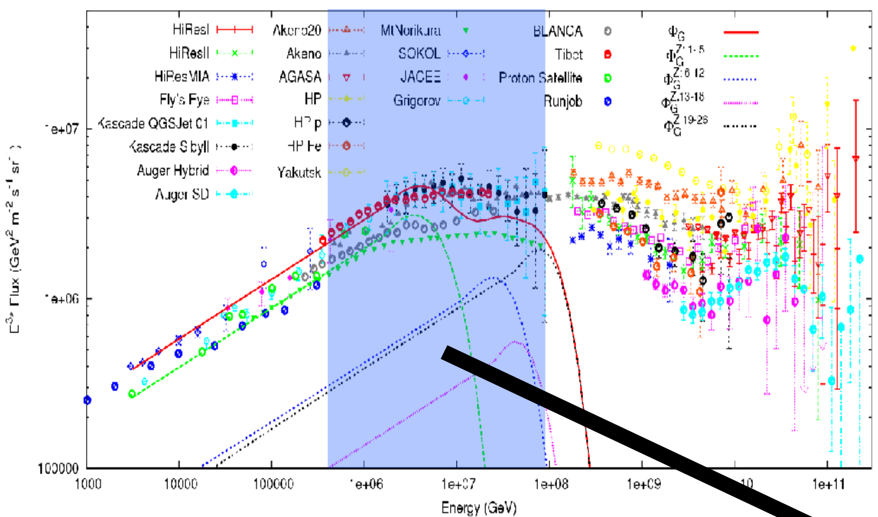
the only SNR data above 30 TeV





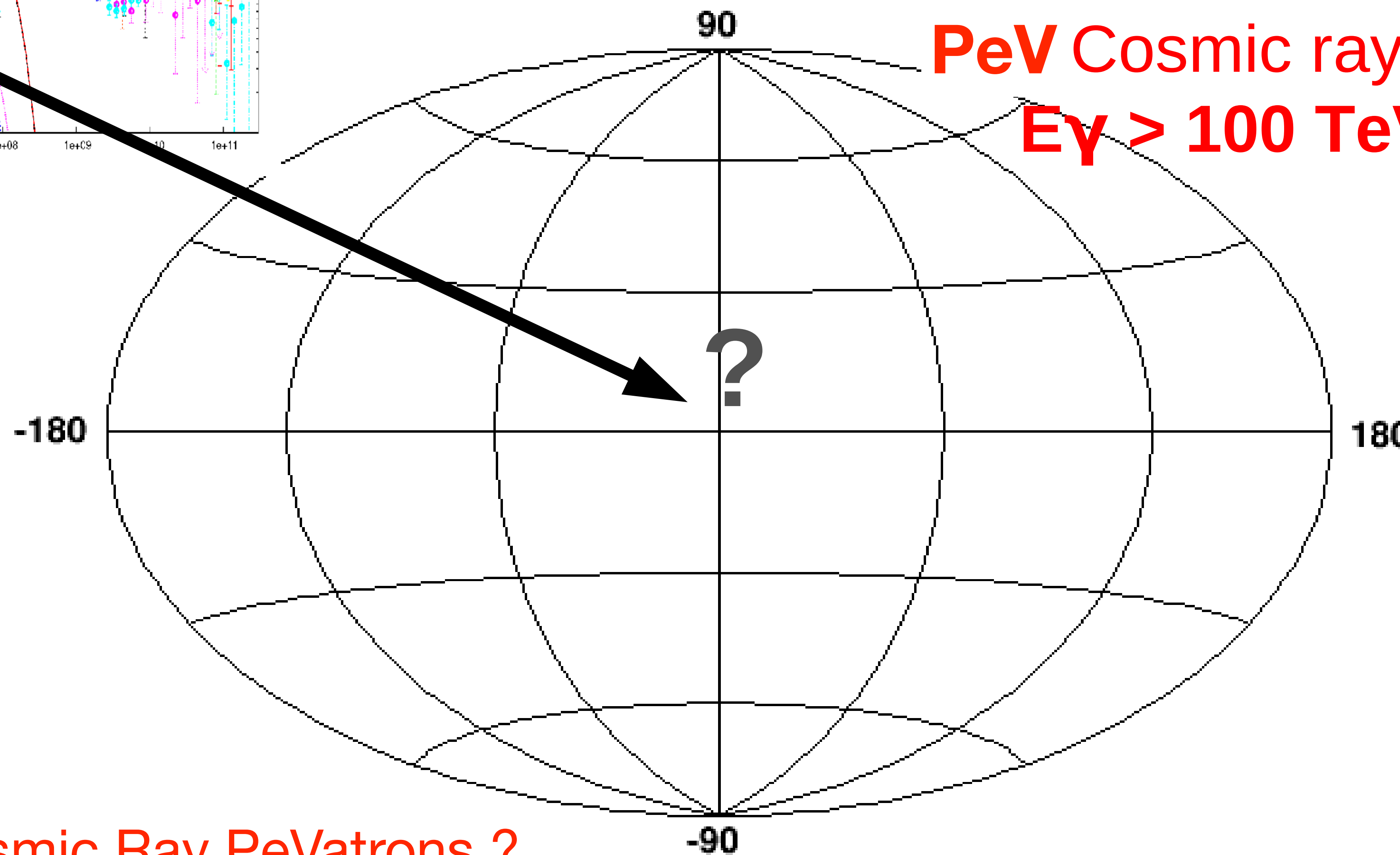
PeVatrons sky

Gammas from Galactic Cosmic rays: $E_\gamma \sim E_{CR}/10$



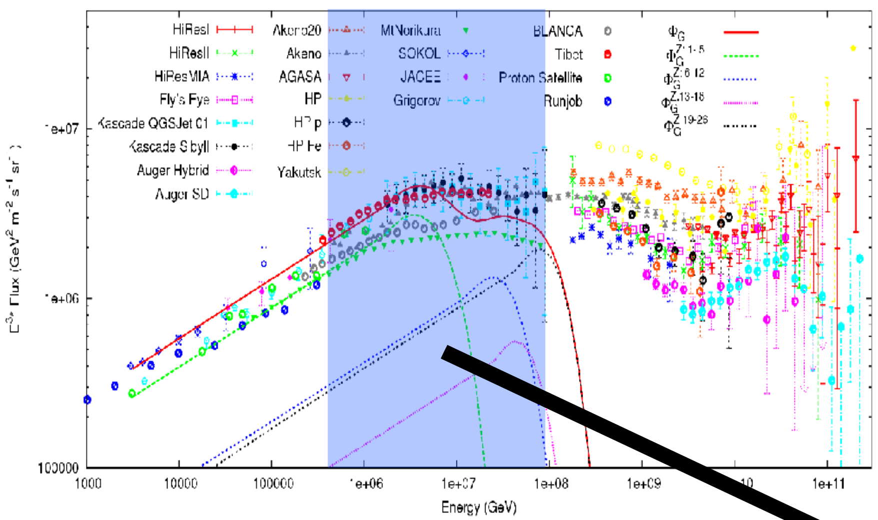
PeV Cosmic rays

Eγ > 100 TeV



Where are the Cosmic Ray PeVatrons ?

PeVatrons sky



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PeV Cosmic rays

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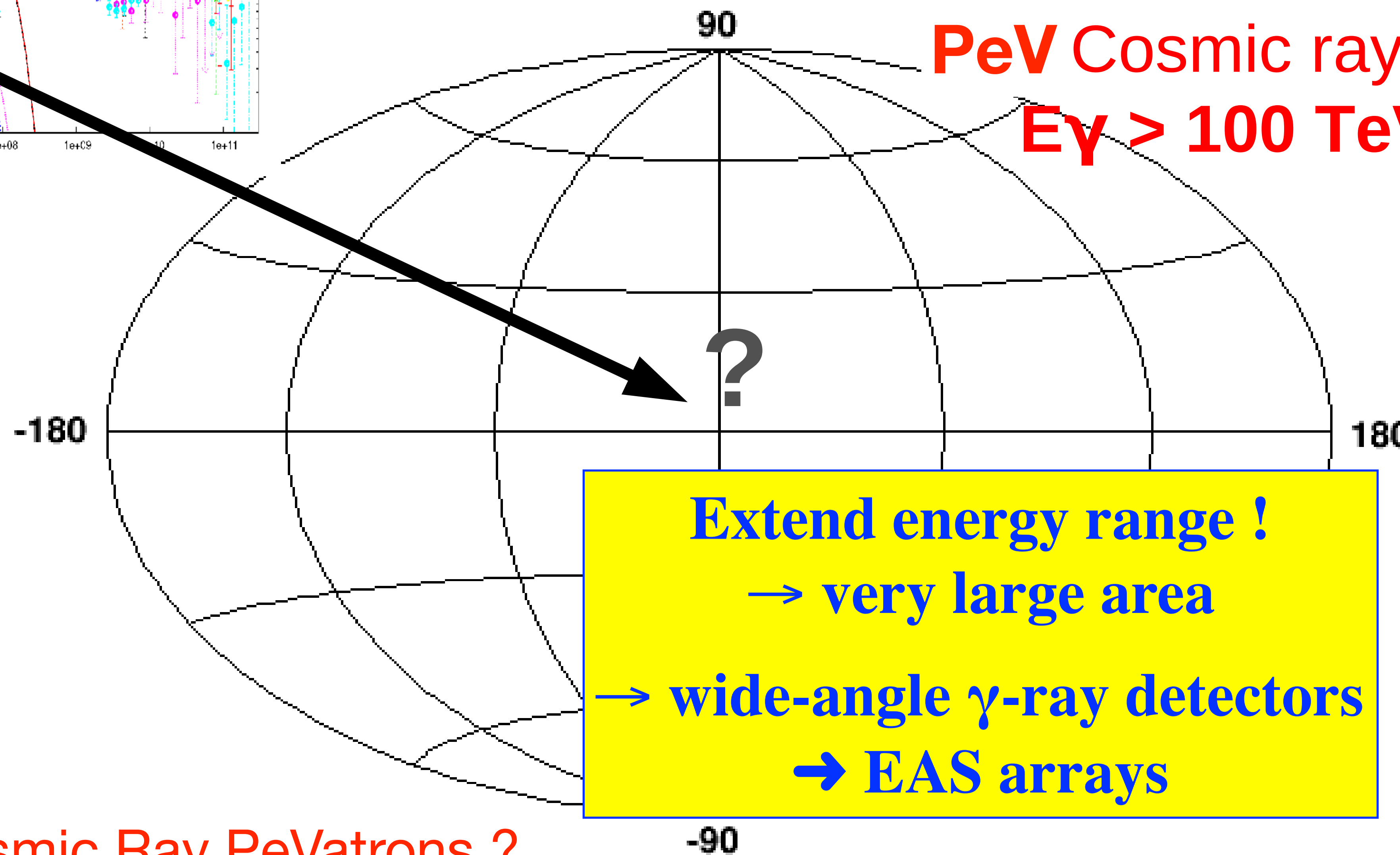


Extend energy range !

→ very large area

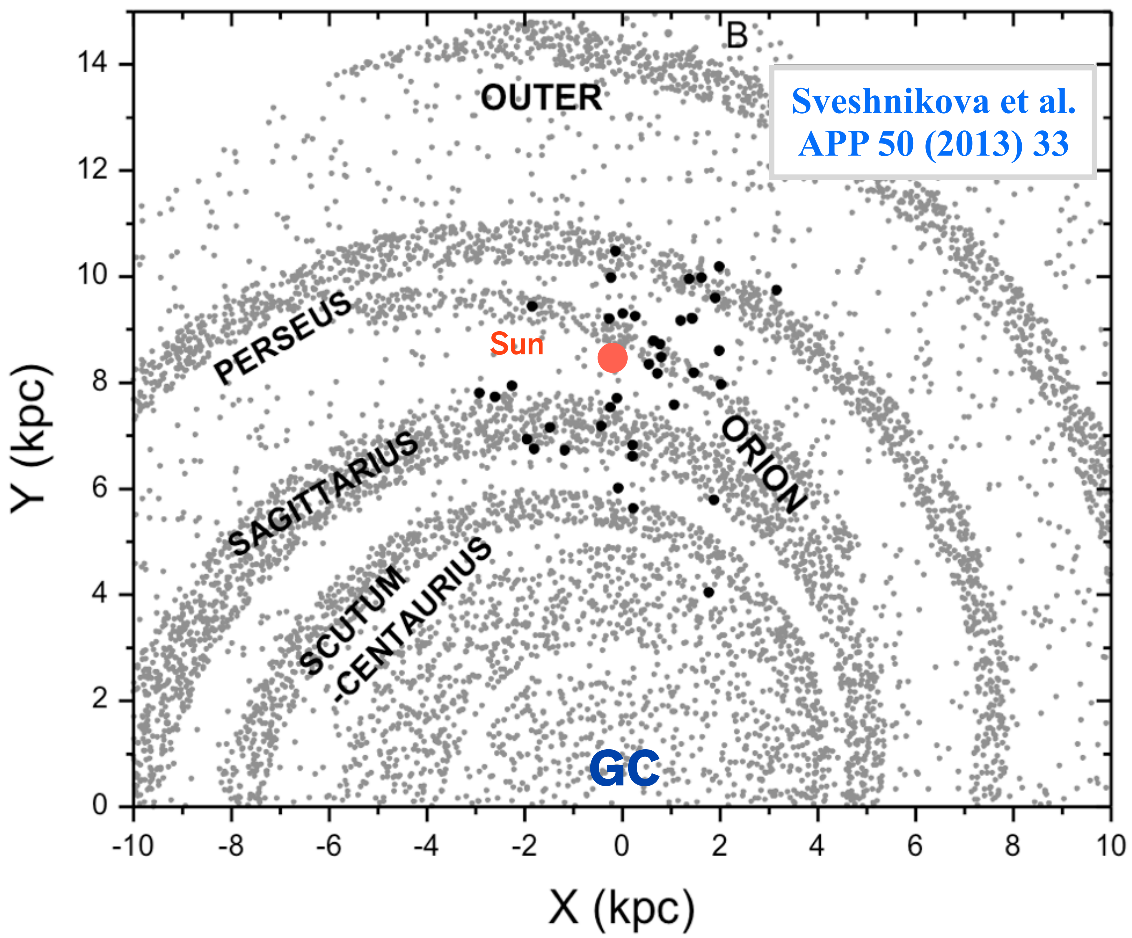
→ wide-angle γ-ray detectors

➜ EAS arrays

Where are the Cosmic Ray PeVatrons ?

Cosmic Ray diffusive propagation and anisotropy

Distribution of nearby SNRs in the Galaxy



Galactic Cosmic Rays

- Accelerated in SNRs
- Propagate diffusively

Consequences for anisotropy

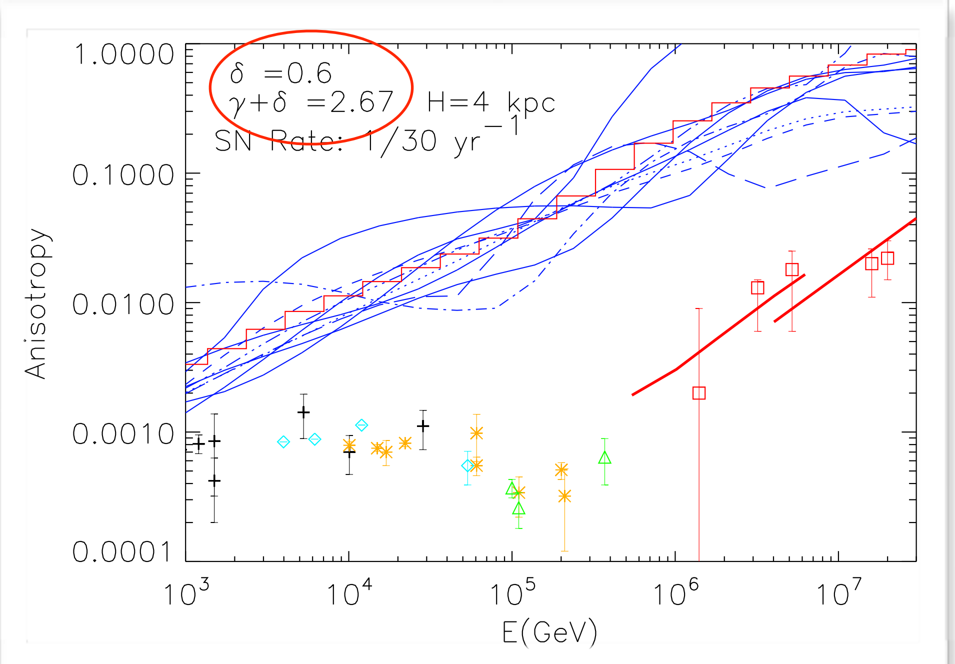
- CR density gradients are visible as anisotropy
- Anisotropy amplitude $\lesssim 10^{-2}$
- Amplitude increases with energy
- Dipole shape
- Phase pointing towards the most significant sources

Generally speaking, the dipole component of the anisotropy is believed to be a tracer of the CR source distribution, with the largest contribution from the nearest ones.

Measuring the anisotropy of CRs provides important information on the propagation mechanisms and the identification of their sources.

The *‘CR anisotropy problem*’

- CRs scatter in the turbulent Galactic magnetic field (GMF) and their propagation is believed to be diffusive.
- In this framework the only deviation from an isotropic CR arrival direction distribution is in the form of a dipole anisotropy.



Strong et al. 2007
Erlykin & Wolfendale 2006
Blasi & Amato 2012
Pohl & Eichler 2013
Zirakashvili & Ptuskin 2012
Giacinti & Sigl 2012

Models considering the isotropic diffusive propagation of CRs in the Galaxy generally predict a much higher large-scale anisotropy in the multi-TeV energy band than observed (≲ 0.1%).

One requires a residence time in the galaxy $\propto E^{-0.6}$ to turn a source spectrum $E^{-2.1}$ into the observed spectrum $E^{-2.7}$.

Such a large fall in trapping time at high energies implies a rapid outflow of particles from the galaxy at very high energies, of which there is no sign.

- Models with smaller δ, in better agreement with anisotropy data, require too steep source spectra to reproduce the observed spectra.
- Models with δ ≳ 0.5, preferred on the basis of CR spectral data, face major problems with the observed Large Scale CR Anisotropy.

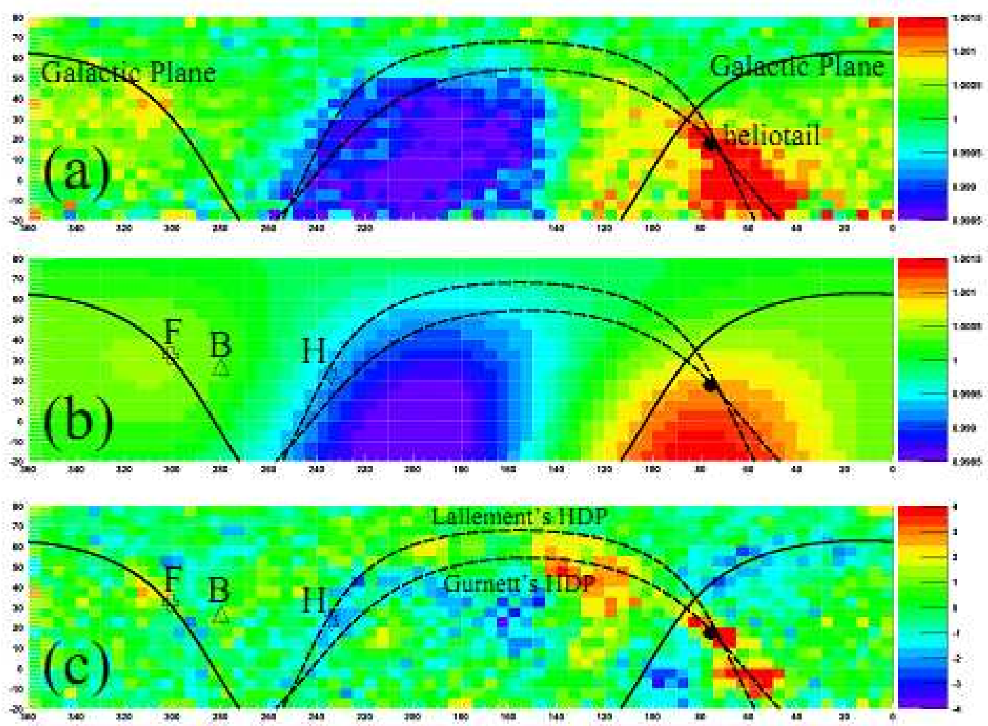
The ‘anisotropy problem’ is the most serious challenge to the standard model of the origin of galactic CRs from diffusive shock acceleration.

Hillas 2005

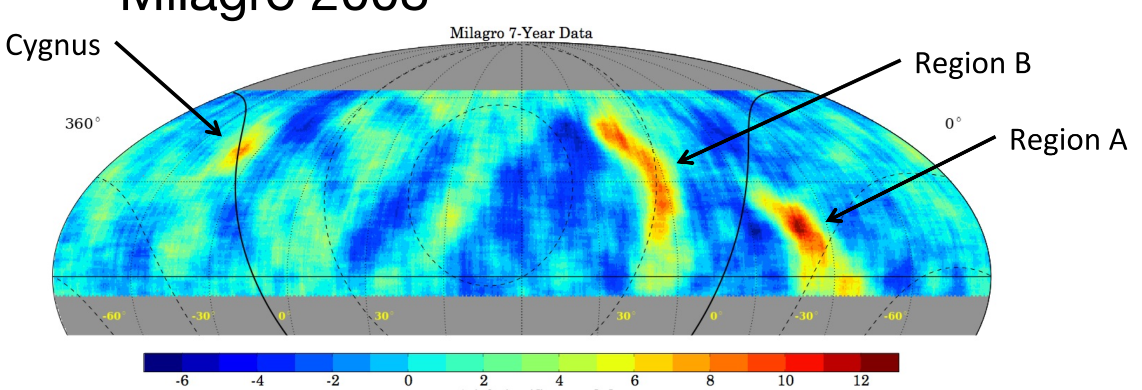
Medium Scale Anisotropy

CR anisotropy is **not a dipole**

Tibet ASγ 2007

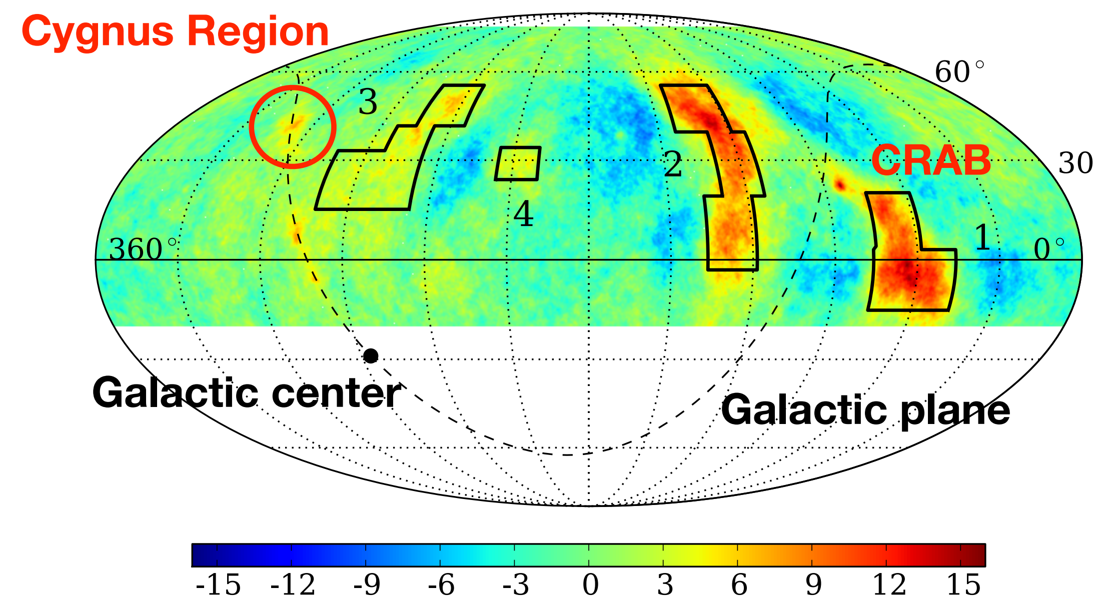


Milagro 2008

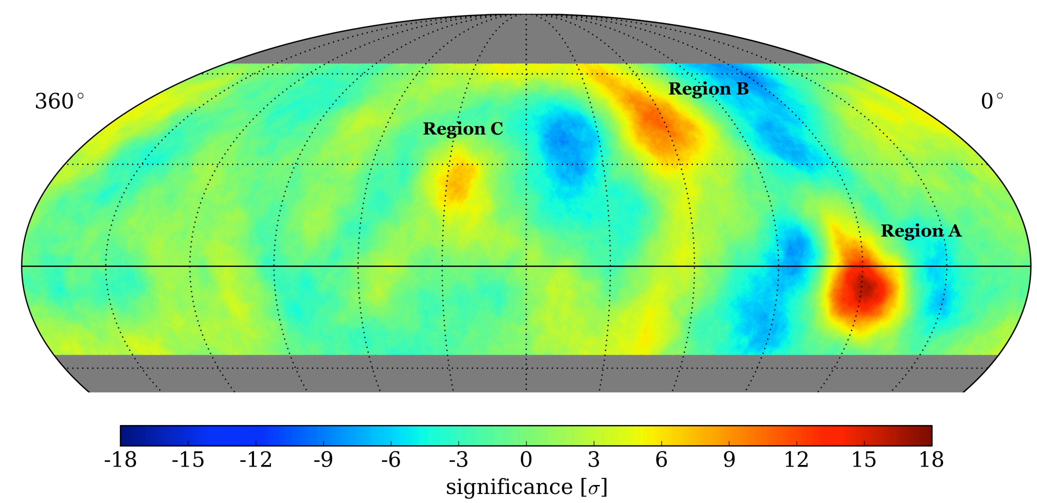


A. Abdo et al., PRL **101**:221101, 2008

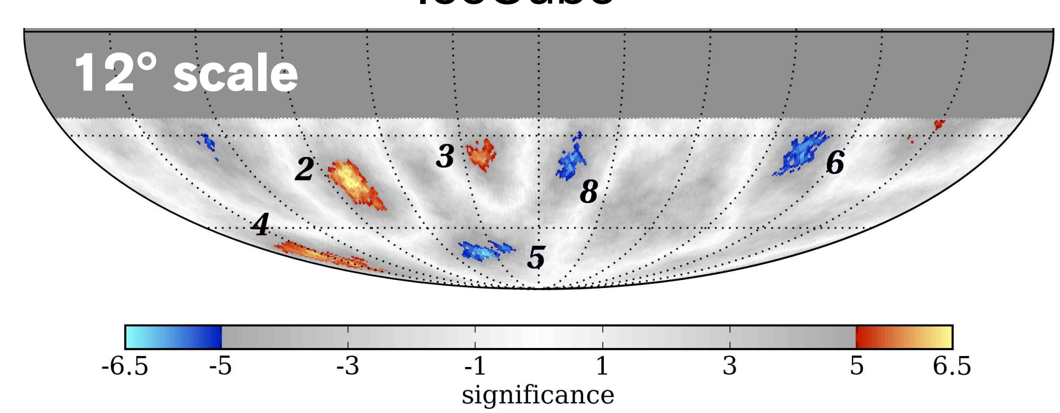
ARGO-YBJ



HAWC



IceCube



Why the dipole ?

Very common sentence in theoretical papers in the last 10 years:

“The large scale anisotropy can be explained within the diffusive approximation.”

Strong et al. 2007
Erlykin & Wolfendale 2006
Blasi & Amato 2012
Pohl & Eichler 2013
Zirakashvili & Ptuskin 2012
Giacinti & Sigl 2012

What do authors mean with “large-scale”?

Models based on the diffusion approximation foresee a dipole, i.e. the sentence would be true if “*large-scale*” meant “*one single excess as wide as 180°*”

Why the dipole ?

★ First (and easiest) component to detect experimentally (but underground experiments did better already decades ago).

★ Theoretically, it is the easiest component to (try to) relate to Physics.

- Even considering the space as an isotropic medium of propagation, one source emitting CRs would generate a dipolar anisotropy.
- When there are several sources the corresponding dipole anisotropies compose in a result dipole. Therefore, if the CR propagation is isotropic, we expect a dipole anisotropy pointing towards the average position of CR sources.
- Whichever motion of the laboratory reference frame with respect to an isotropic CR plasma would result in a dipole.
- In general, composing dipoles result in a dipole.

Probing sources & propagation of CRs ?

- **propagation effect from turbulent realization of interstellar magnetic field within scattering mean free path**

Giacinti & Sigl, 2012

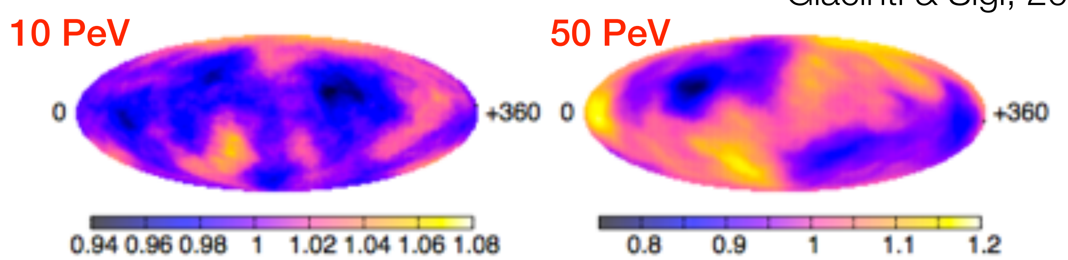


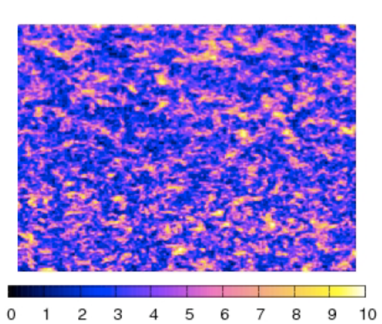
FIG. 1. Renormalized CR flux predicted at Earth for a concrete realization of the turbulent magnetic field, *after subtracting the dipole* and smoothing on 20° radius circles. Primaries with rigidities $p/Z = 10^{16}\,\mathrm{eV}$ (*left panel*) and $5 \times 10^{16}\,\mathrm{eV}$ (*right panel*). See text for the field parameters and boundary conditions on the sphere of radius $R = 250\,\mathrm{pc}$.

The medium and small scale anisotropies necessarily appear on the sky, provided that there exists a large scale anisotropy.

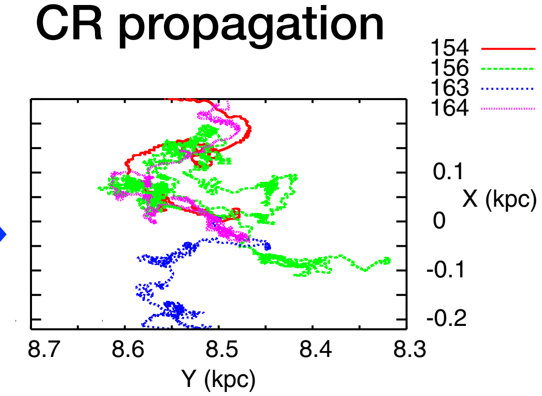
The small scale anisotropies are due to the structure of the local turbulent GMF, typically within the scattering length from Earth.

"For distances from the source less than the diffusion length, the propagation in the local turbulent magnetic field still has memory: the particle trajectories are locally determined by their initial directions, and a very small change of the initial angle would not lead to very significantly different trajectories."

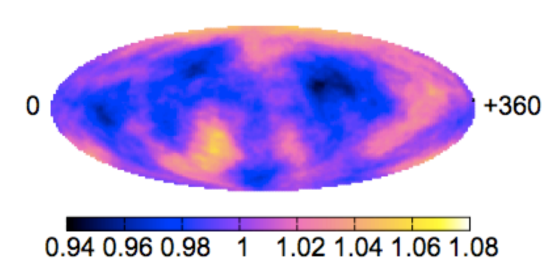
Turbolent GMF



CR propagation



small scale anisotropy



Probing sources & propagation of CRs ?

- **propagation effect from turbulent realization of interstellar magnetic field within scattering mean free path**

anomalous anisotropy structure spontaneously generated from a global dipole anisotropy as a consequence of Liouville Theorem in the presence of a local turbulent magnetic field

CR diffusive propagation ➡ Dipolar flux (≈ large scale anisotropy)

CR diffusive propagation in local turbolent GMF ➡ small anisotropies

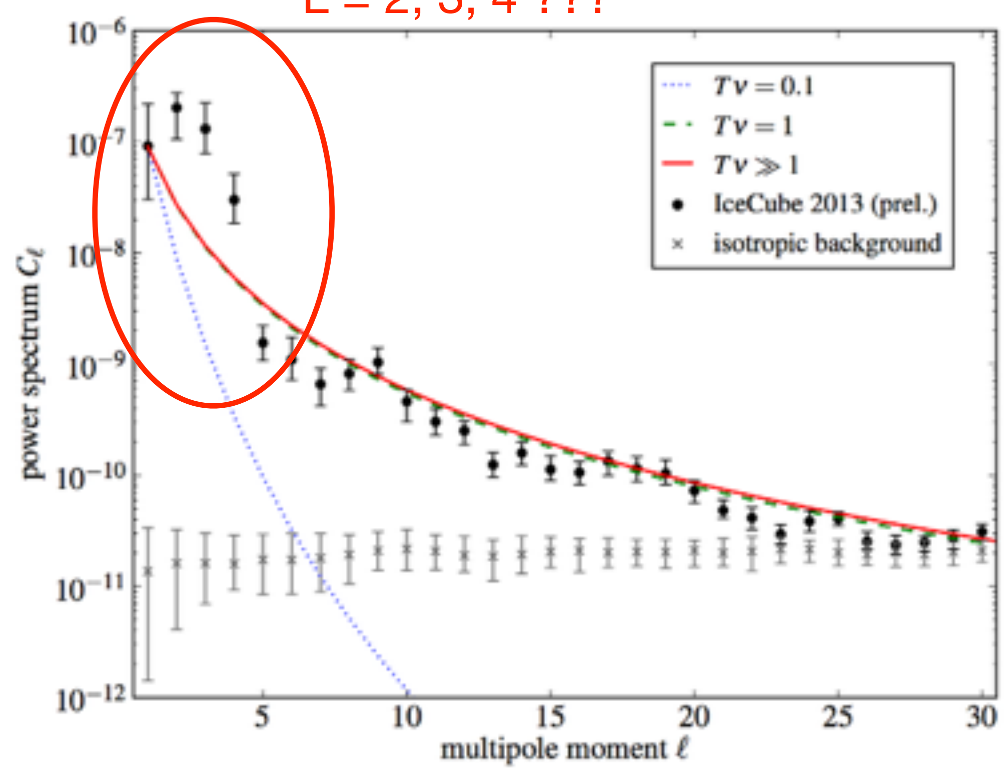
good correlation of the CR angular power spectrum with the frequency spectrum of galactic magnetic fields

νT is the time in units of “relaxation time” (ν is the relaxation rate).
The higher the multipole, the closer its value to asymptotic values.

CRs virtually lose memory of times longer ago than T, and their propagation is uncorrelated with initial conditions.

L = 2, 3, 4 ???

Ahlers, 2014

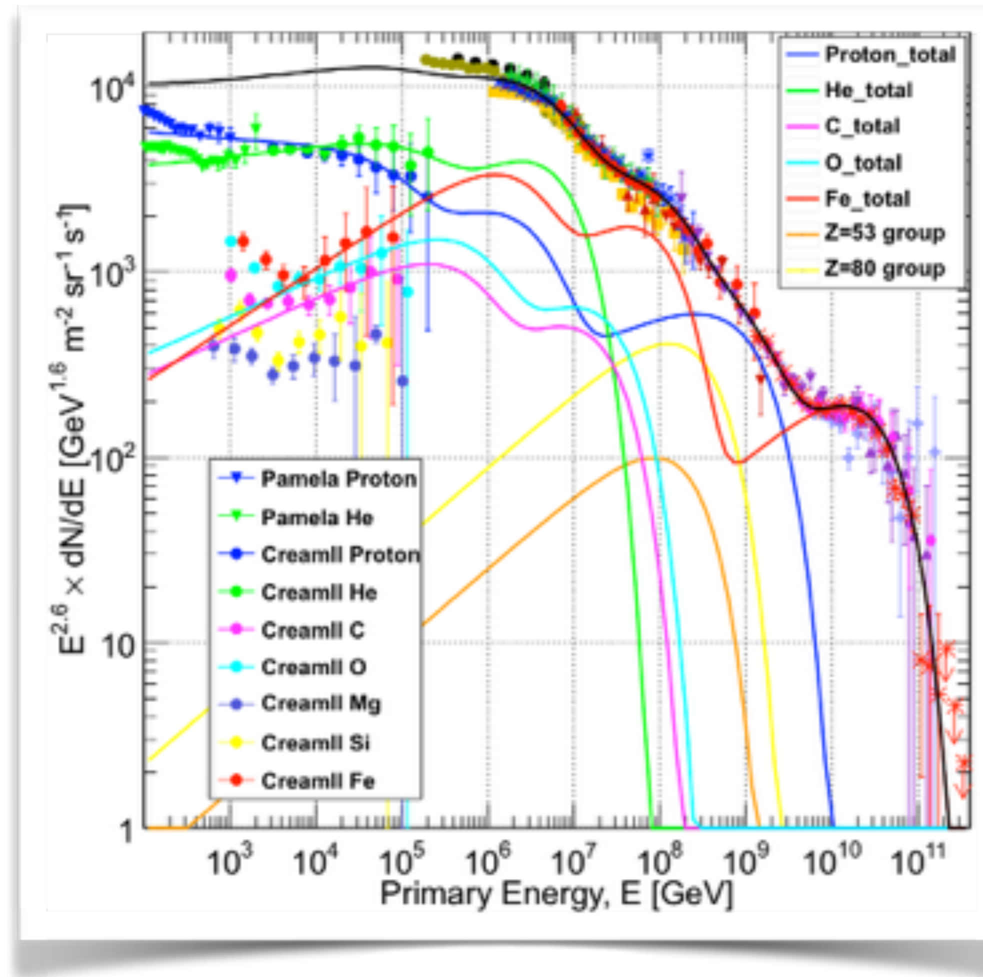


Large non turbolent contributions at low multipoles ?!

New generation EAS-array to open the way to *multi-scale sky survey*, allowing to relate the angular power spectrum to the frequency spectrum of galactic magnetic fields.

Energy Spectrum, Anisotropy & Mass Composition

The measurement of CR energy spectrum, mass composition and anisotropy inevitably probes the properties and spatial distribution of their sources as well as of the long propagation journey through the magnetized medium.



In fact, propagation of CRs in the galactic medium is known to affect their spectrum and direction distribution.

The determination of the CR arrival direction does not depend on knowledge of the mass of the primary particle, however, the use of combined data on the energy spectrum and arrival direction distribution requires the knowledge of the primary mass distribution to discriminate between different origin and propagation models.

➡ study **correlation** between anisotropy & spectral anomalies vs **primary mass**

➡ New generation EAS-array !

Approaching the knee

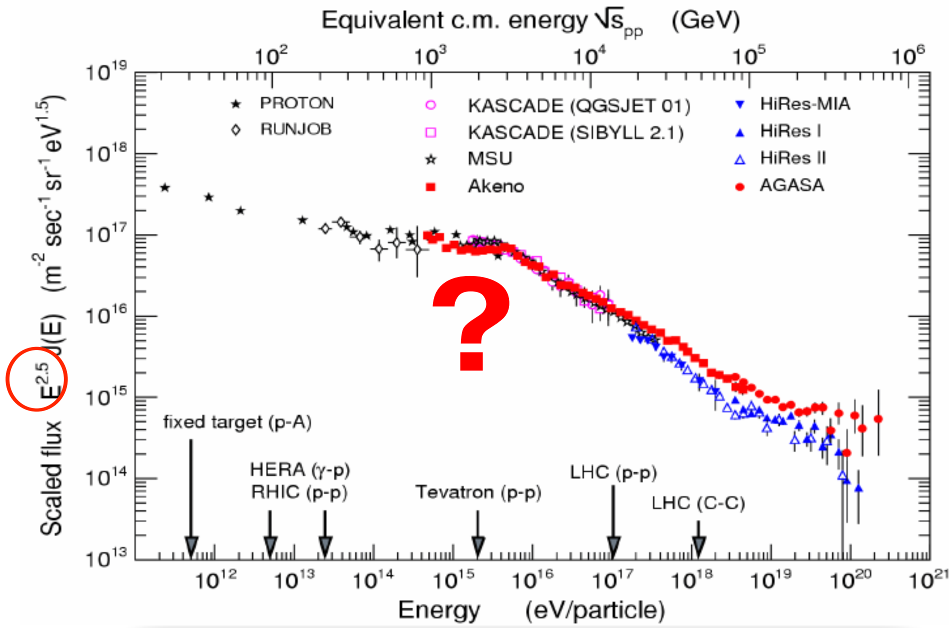
How well do we know the structure of the primary spectrum around the knee ($10^{14} - 10^{16}$ eV) ?

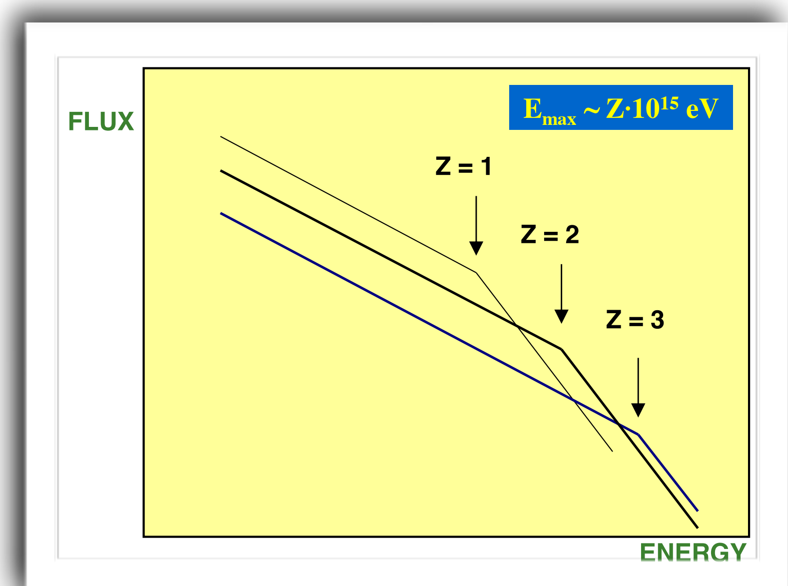
The standard model:

- Knee attributed to light (proton, helium) component
- Rigidity-dependent structure (Peters cycle): cut-offs at energies proportional to the nuclear charge $E_Z = Z \times 4.5$ PeV
- The sum of the flux of all elements with their individual cut-offs makes up the all-particle spectrum.
- Not only does the spectrum become steeper due to such a cutoff but also heavier.

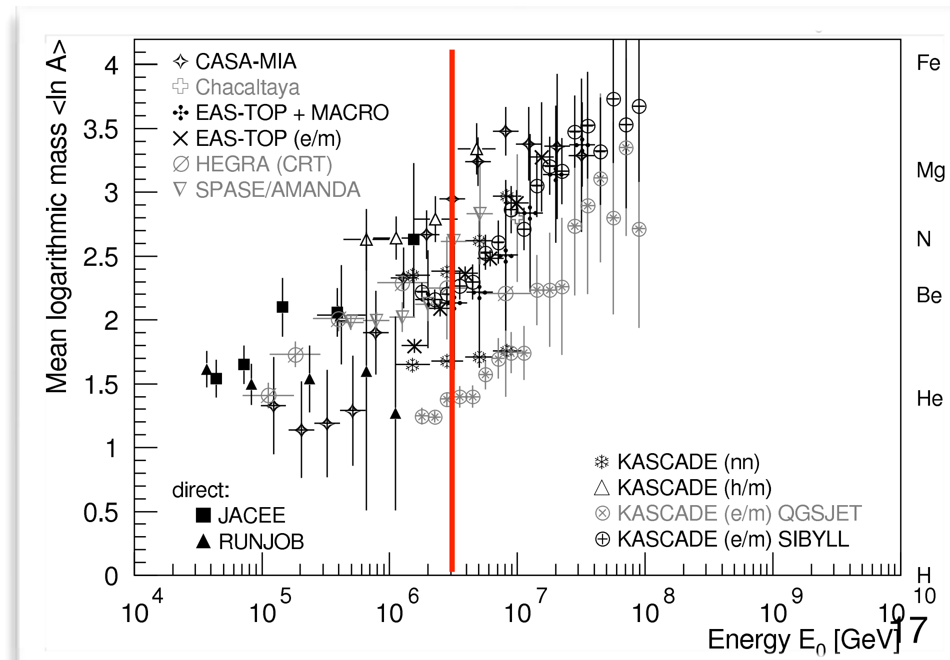
But

Experimental results still conflicting !





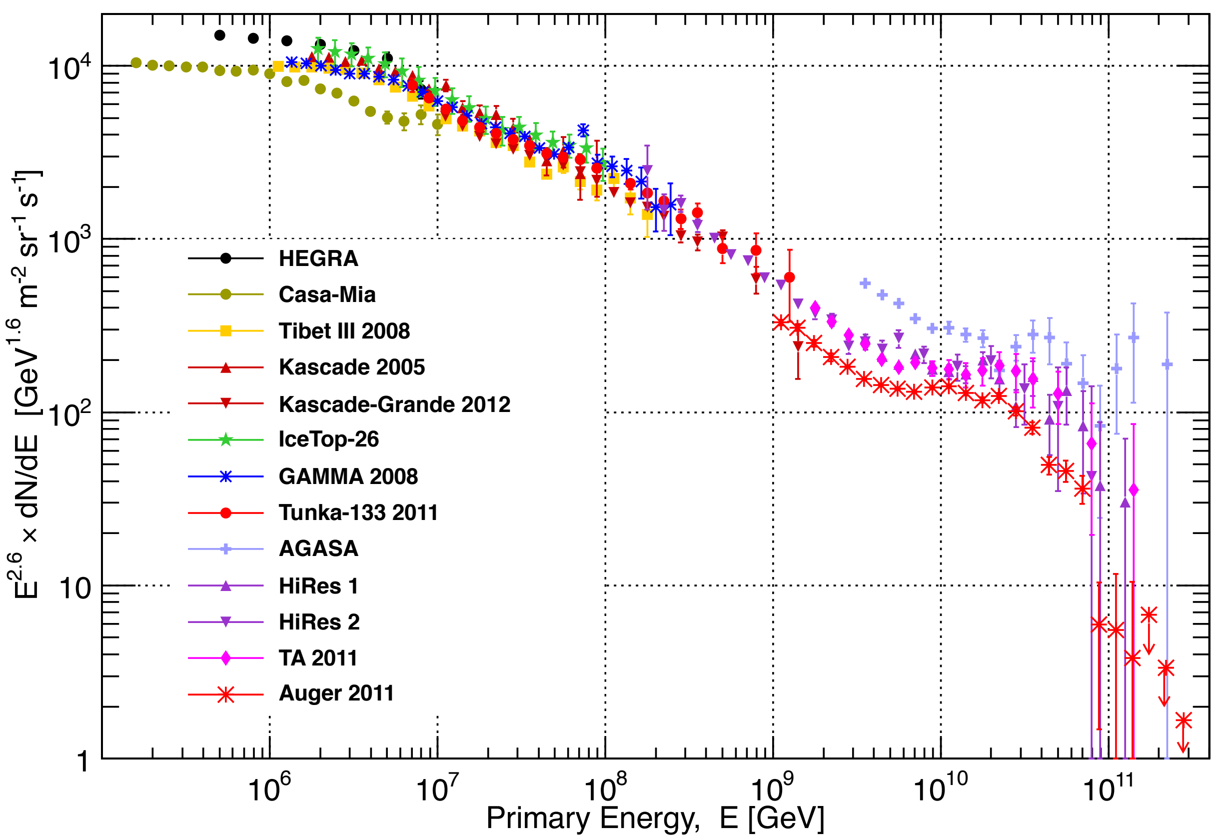
E_{max}(iron) = 26 · E_{max}(proton)



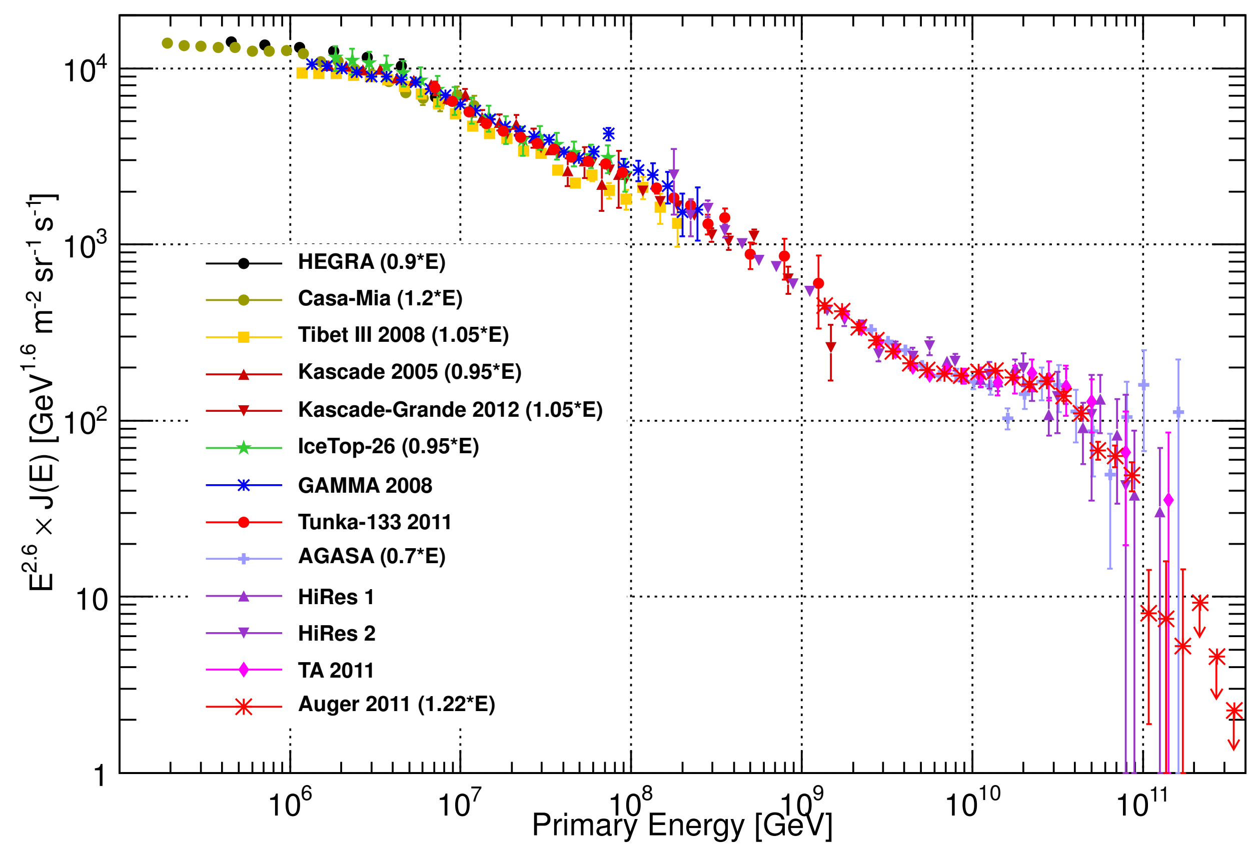
Energy Calibration

All particle spectra obtained shifting the energies by a factor smaller than what can be estimated as systematic error: i.e. 15-20%

Serap Tilav, ISVHECRI 2014



Before shifting



After shifting energy scales

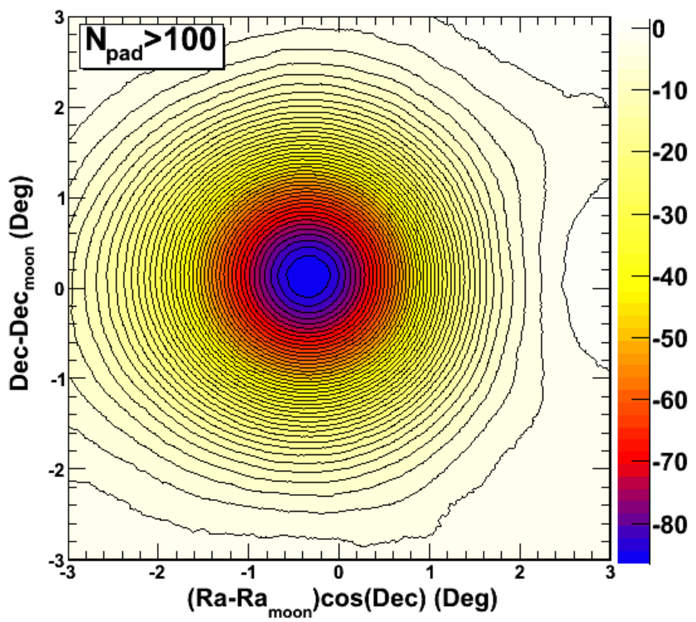
Difference between measurements can be mainly attributed to systematic effects in the energy calibration

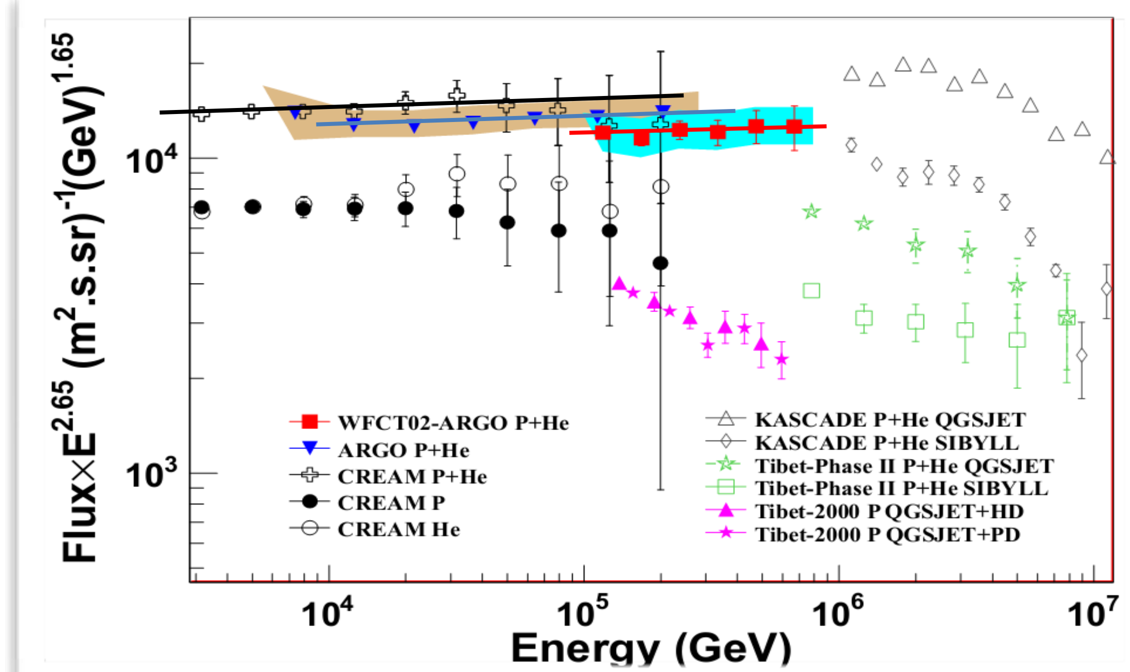
Overposition with direct measurements crucial ➜ low energy threshold

Calibration of the energy scale

(p+He) spectrum (2 - 700) TeV

ARGO-YBJ: *Moon shadow* tool





Bartoli et al., Chin. Phys. C 38, 045001 (2014)

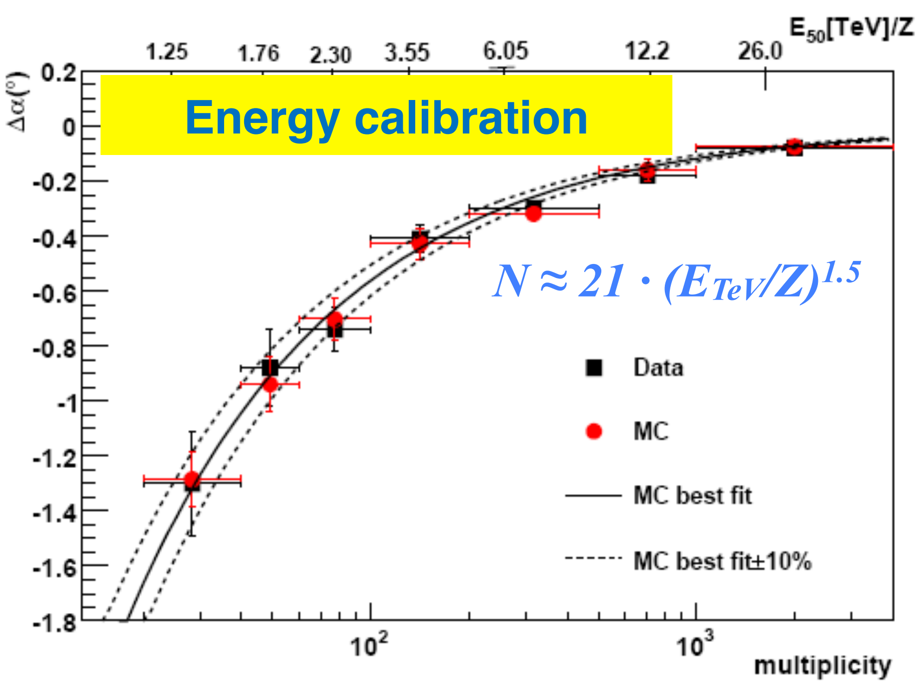
The energy scale uncertainty is estimated at 10% level in the energy range 1 – 30 (TeV/Z).

- CREAM: $1.09 \times 1.95 \times 10^{-11}$ (E/400 TeV)$^{-2.62}$
- ARGO-YBJ: 1.95×10^{-11} (E/400 TeV)$^{-2.61}$
- Hybrid: $0.92 \times 1.95 \times 10^{-11}$ (E/400 TeV)$^{-2.63}$

Single power-law: 2.62 ± 0.01

Flux at 400 TeV:

$1.95 \times 10^{-11} \pm 9\%$ (GeV^{-1} m^{-2} sr^{-1} s^{-1})

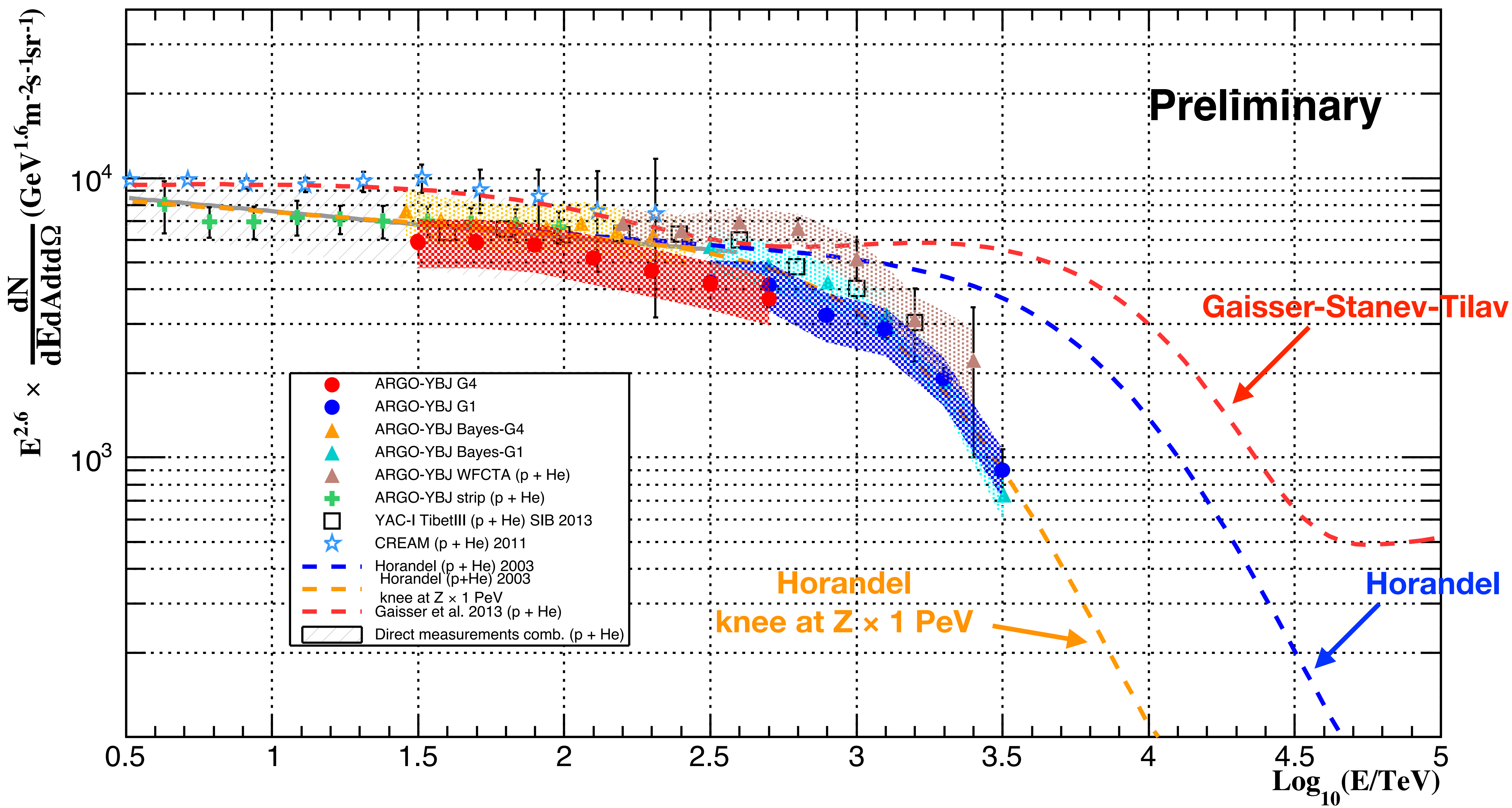


The 9% difference in flux corresponds to a difference of ± 4% in energy scale between different experiments.

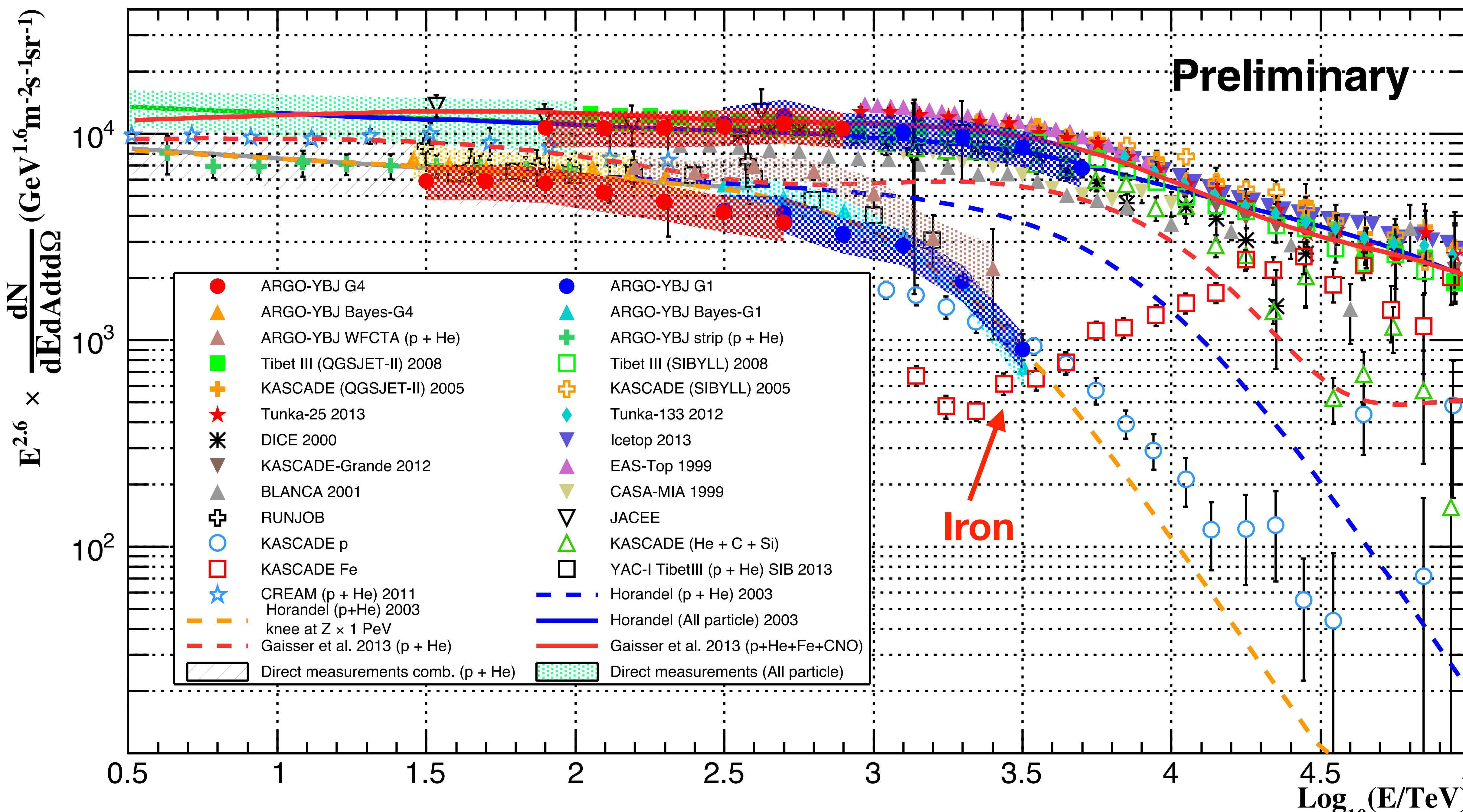
Low energy threshold important !

Light component spectrum (3 TeV - 5 PeV) by ARGO-YBJ

Comparison with direct measurements and with Tibet ASgamma (SYBILL)



The overall picture



➡ New generation EAS-array to trace the heavy component up to 10^{18} eV !

Questions to the knee energy range

Cosmic Ray sources (*‘PeVatrons’*) → **Still open**

Observation of gamma-ray sky above 100 TeV !

Composition at the knee ?
Rigidity – dependent knee ? → **Still open**

Observation of proton (ARGO-YBJ ?) and iron knees !

Anisotropy ? → **Totally open**

Spectroscopy of the anisotropy regions !

End of Galactic spectrum ?
Transition galactic - xgalactic ? → **Open**

Energy spectrum and composition with high resolution !

Hadronic interaction models ? → **Still uncertain**

High resolution multi-component measurement !

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Cosmic Ray sources (*'PeVatrons'*) → Still open

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Rigidity – dependent knee ? → Still open

Observation of proton (ARGO-YBJ ?) and iron knees !

Anisotropy ?

Spec

New generation EAS array working in the 10^{11} - 10^{18} eV energy region !

End of Galactic spectrum ?
Transition galactic - xgalactic ? → Open

Energy spectrum and composition with high resolution !

Hadronic interaction models ? → Still uncertain

High resolution multi-component measurement !

Tibet ASγ upgrades

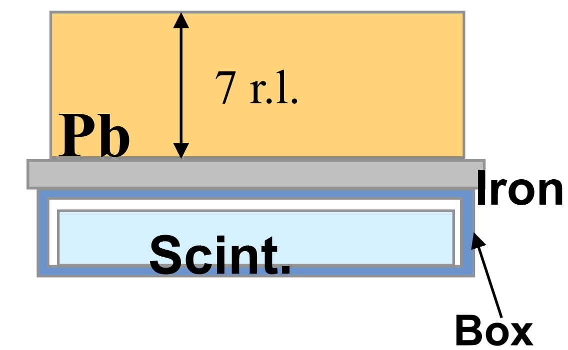
AS array at high altitude (4300m a.s.l.) in operation since 1990

Tibet-III array:37000 m^2 with 789 scint.
YAC array: 500 m^2 with 124 scint.
MD array: 5000 m^2 with 5 pools of water Cherenkov.

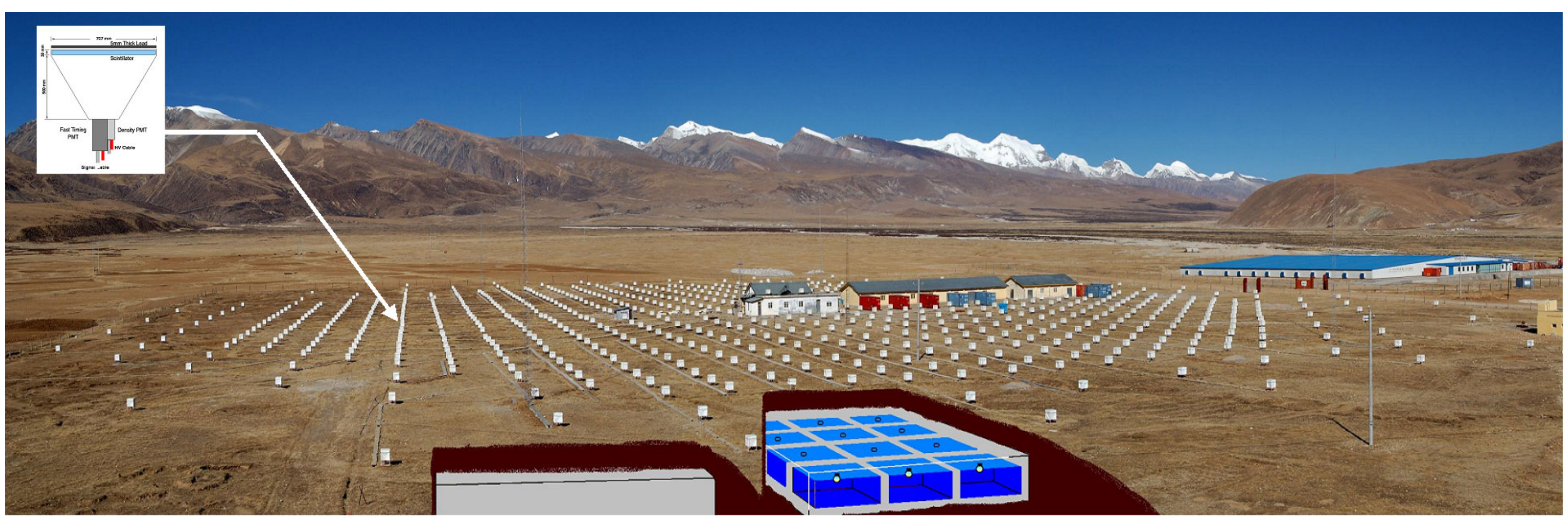
Goal: energy spectrum & composition in the knee energy region through the mesurement of the high energy air shower cores.

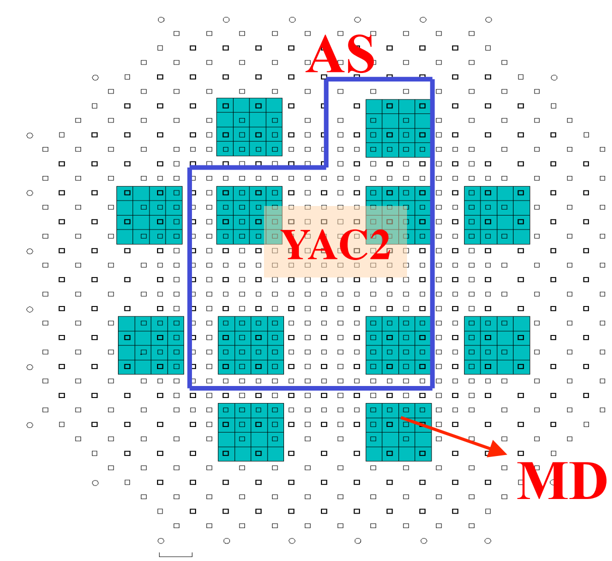
50 TeV – 10^{16} eV

Yangbajing Air shower Core array



Observation of shower electron size under lead plate (burst size N_b) induced by high energy e.m. particles in shower core region.

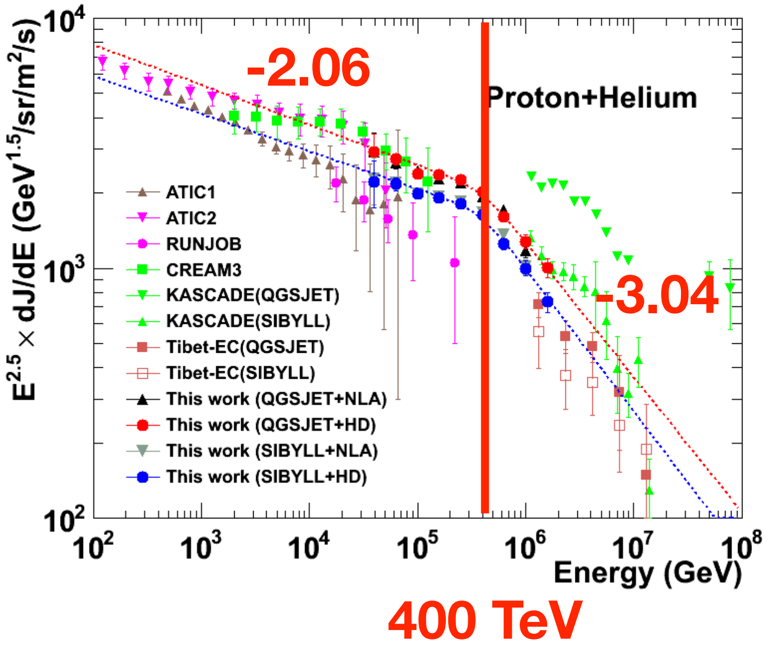


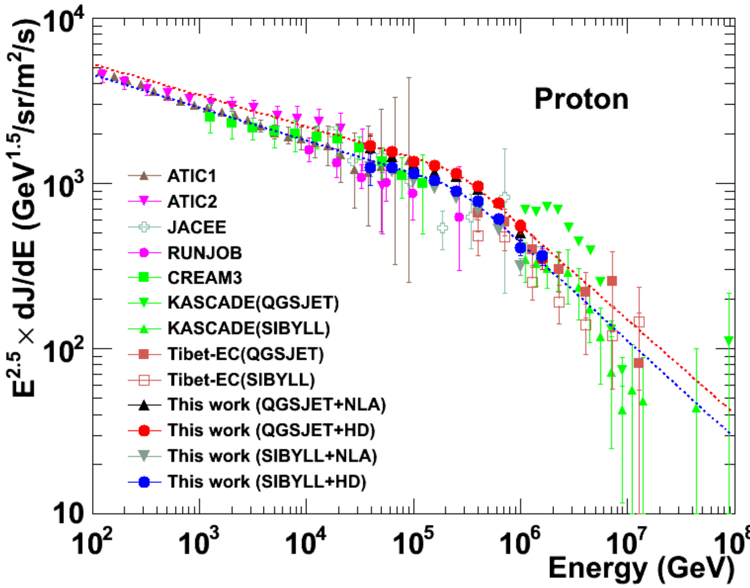


YAC: Yangbajing Air shower Core array

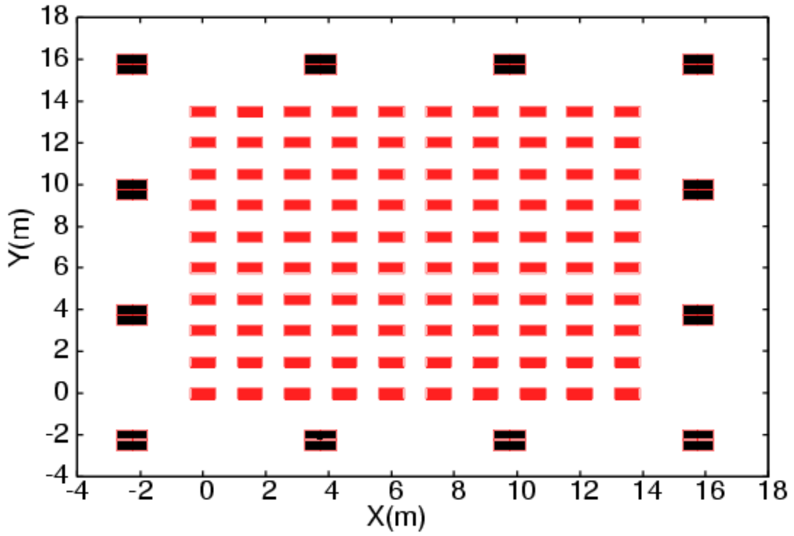
YAC1: a prototype taking data from 2009

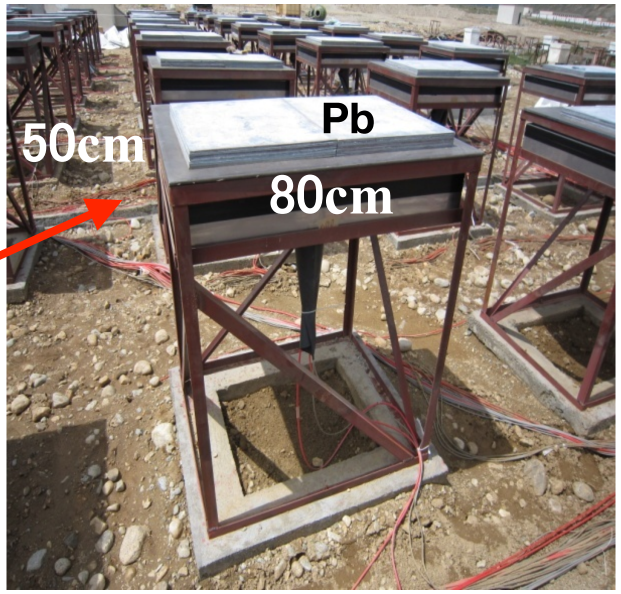
YAC1: first results - ISVHECRI 2012





YAC1: array taking data from 2012



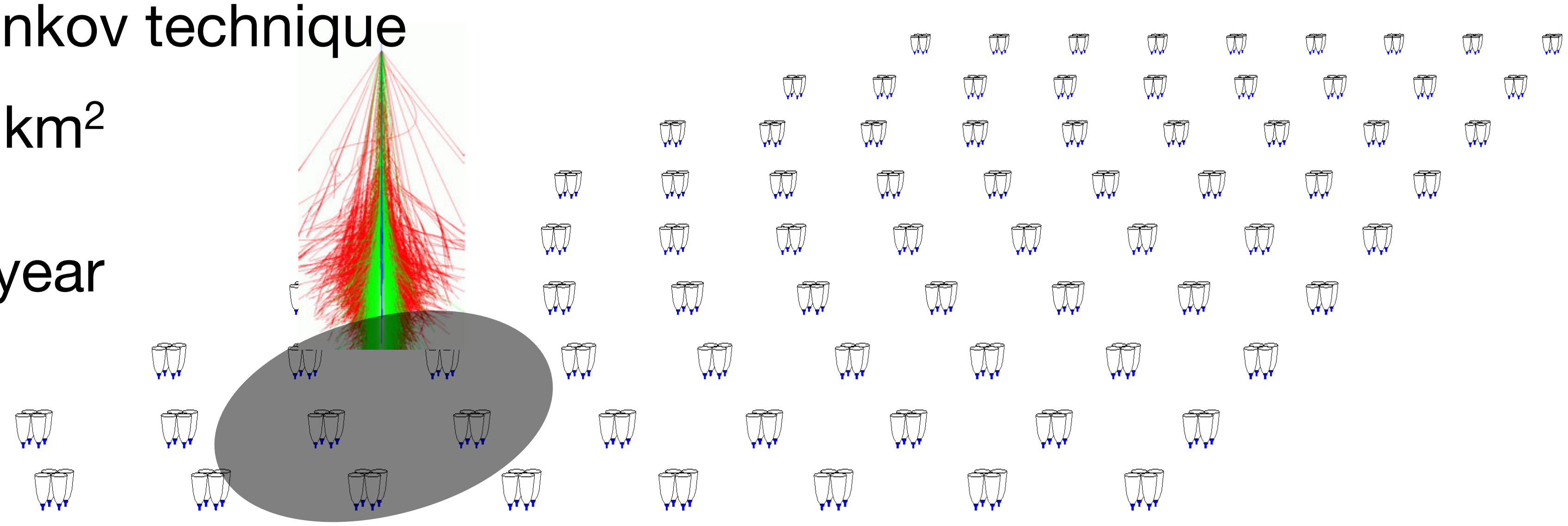


HiSCORE project

Hundred*i **S**quare-km **C**osmic **OR**igin **E**xplorer

Concept: non-imaging air Cherenkov technique

Large area: array up to few 100 km^2
Large Field of view: ~ 0.6 sr
Sky-coverage: > π sr @ 200 h / year



M. Tluczykont et al.: arXiv1403.5688

Prototype-array at Tunka-133:

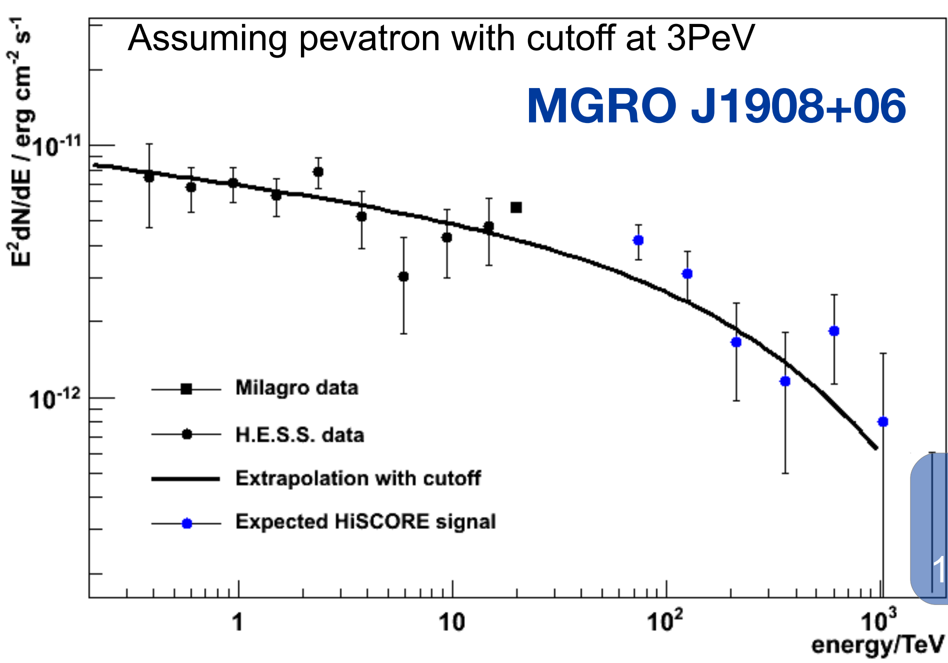
- 9 stations, 300 m × 300 m since October 2013
- 150 m inter-station distance

Optical Station

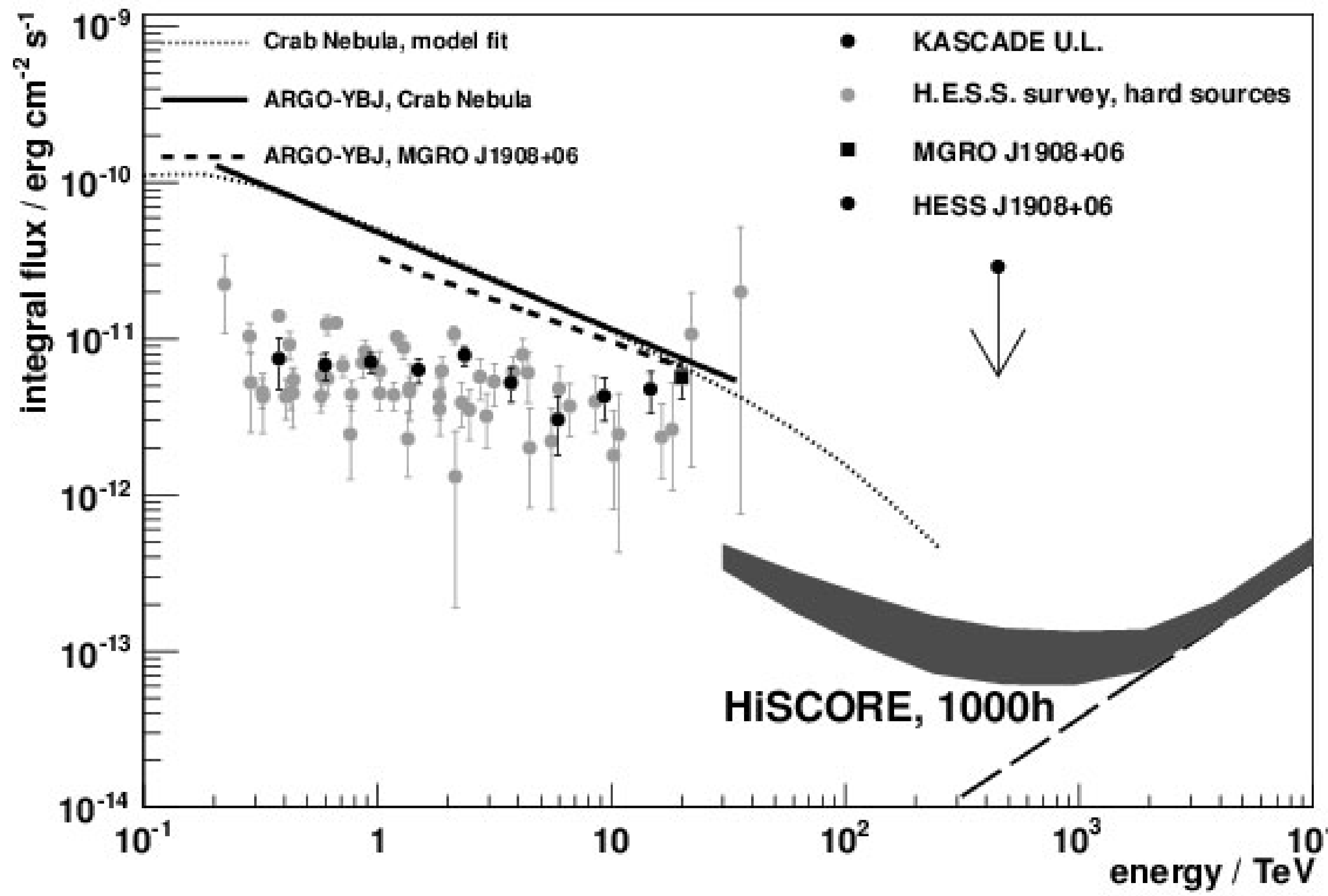
Opening up the Pevatron range: gamma-ray and cosmic-ray astrophysics beyond 10 TeV

HiSCORE Physics Potential

Opening the PeVatron range



10 km²
No μ det.
1 year (200h)



Tluczykont et al. (2014) 2014APh....56...42T

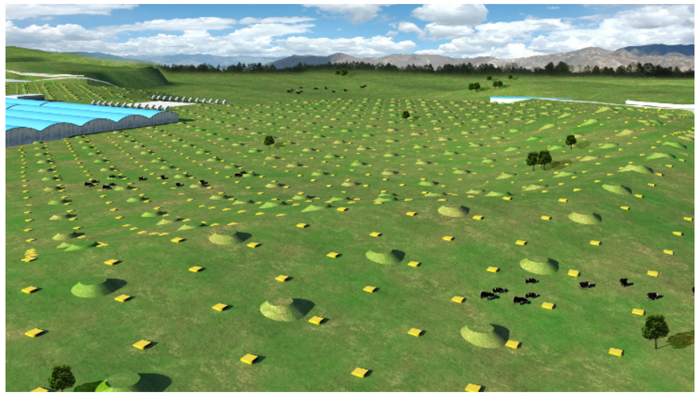
What is LHAASO ?

The Large High Altitude Air Shower Observatory (LHAASO) project is a new generation all-sky instrument to investigate the '*cosmic ray connection*' through a combined study of cosmic rays and gamma-rays in the wide energy range 10^{11} -- 10^{17} eV.

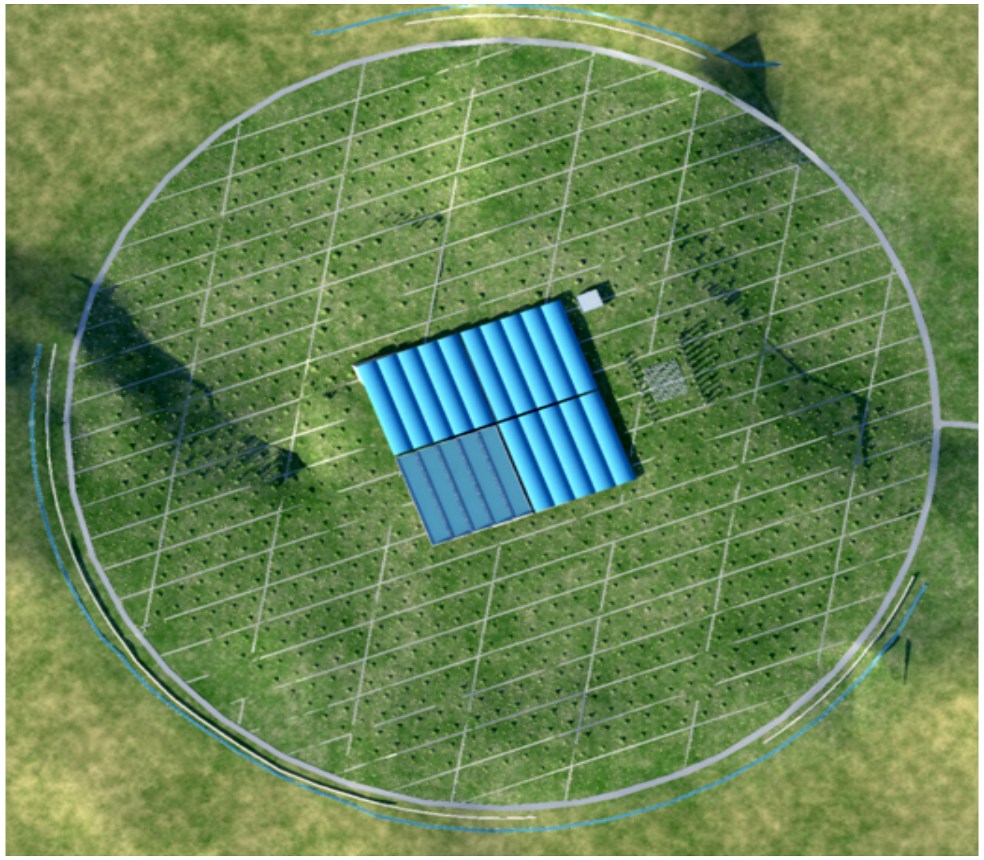
The first phase of LHAASO will consist of the following major components:

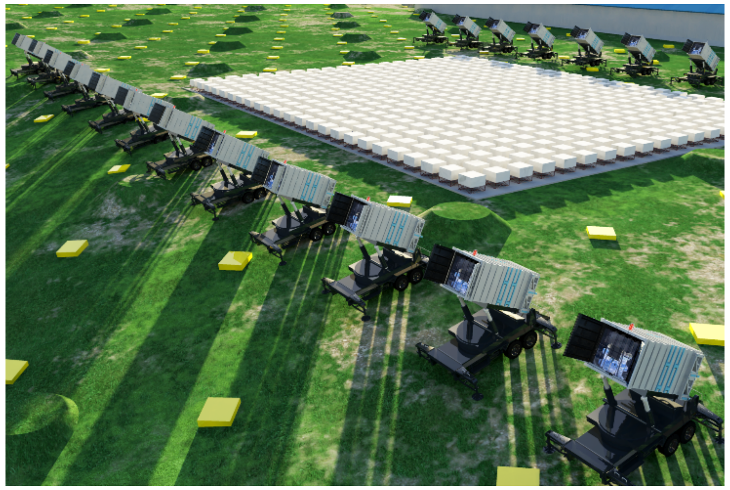
- 1 km^2 array (LHAASO-KM2A), including 5635 scintillator detectors, with 15 m spacing, for electromagnetic particle detection.
- An overlapping 1 km^2 array of 1221, 36 m^2 underground water Cherenkov tanks, with 30 m spacing, for muon detection (total sensitive area 40,000 m^2).
- A close-packed, surface water Cherenkov detector facility with a total area of 90,000 m^2 (LHAASO-WCDA), four times that of HAWC.
- 24 wide field-of-view air Cherenkov (and fluorescence) telescopes (LHAASO-WFCTA).
- 452 close-packed burst detectors, located near the centre of the array, for detection of high energy secondary particles in the shower core region (LHAASO-SCDA).

LHAASO main components



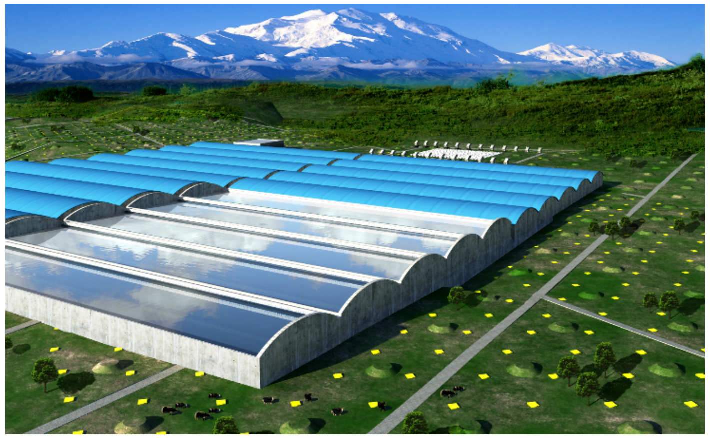
1 KM2A:
5635 EDs
1221 MDs



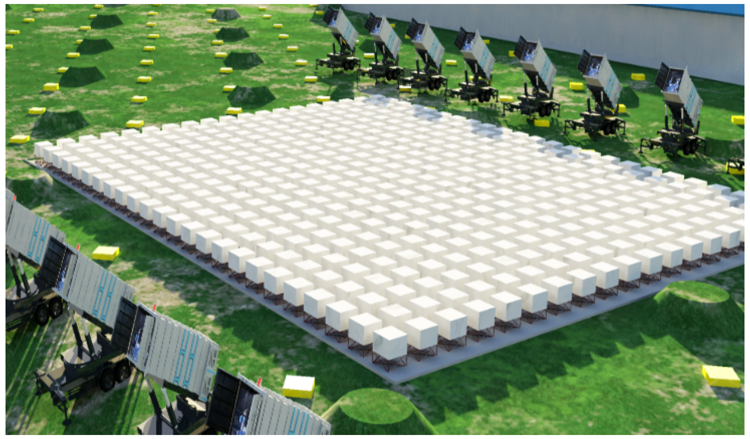


WFCTA:
24 telescopes
1024 pixels each

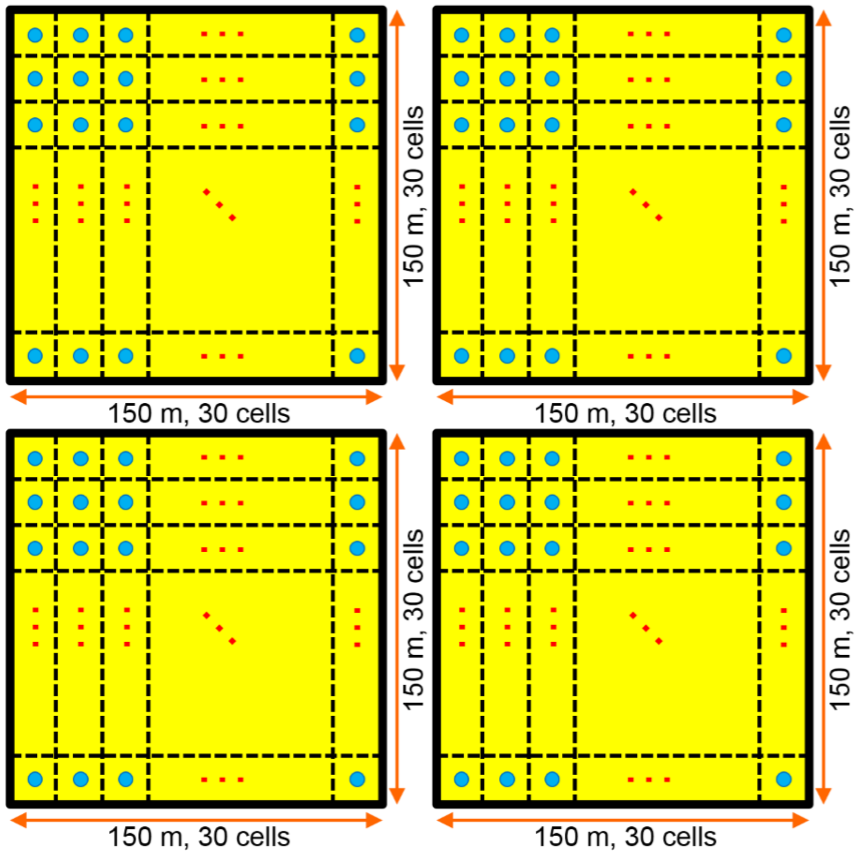
WCDA:
3600 cells
90,000 m^2

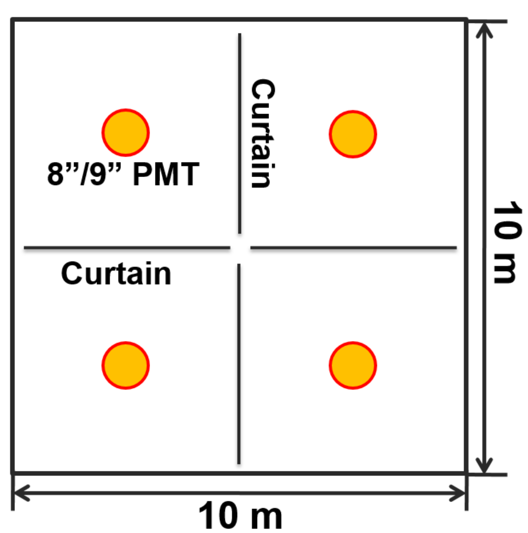


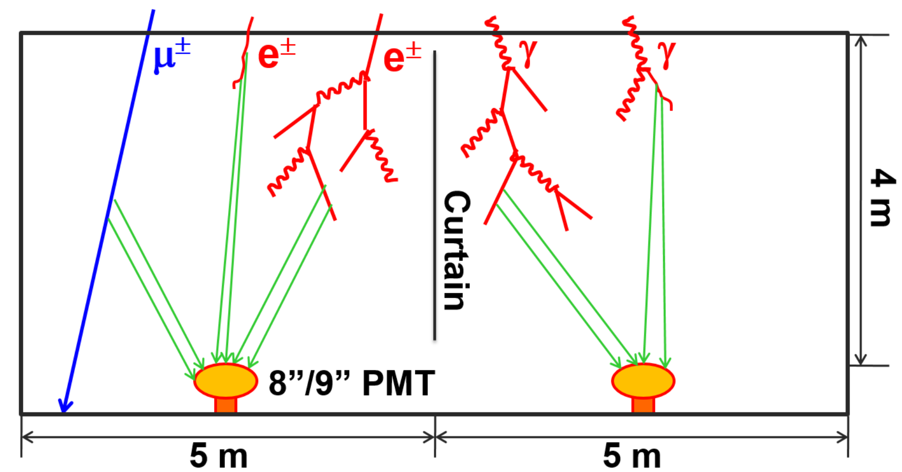
SCDA:
452 detectors



Water Cherenkov Detector Array

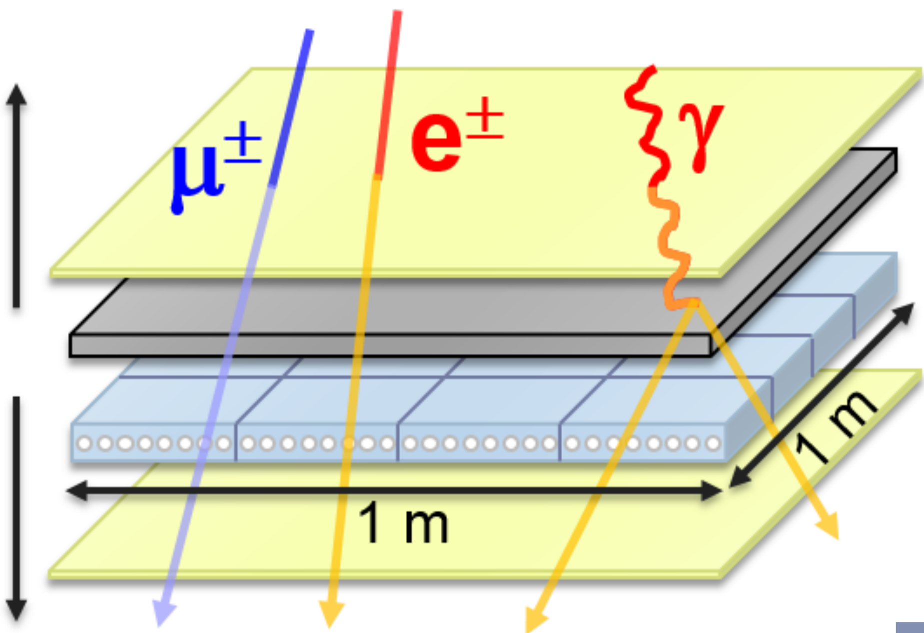


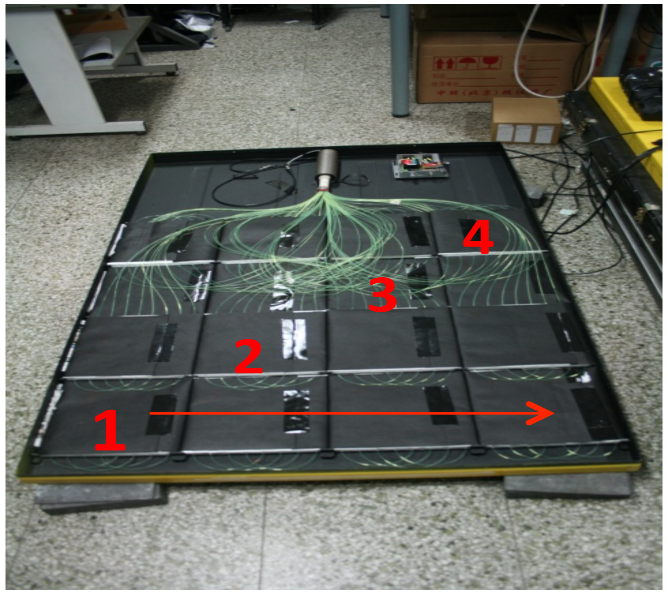


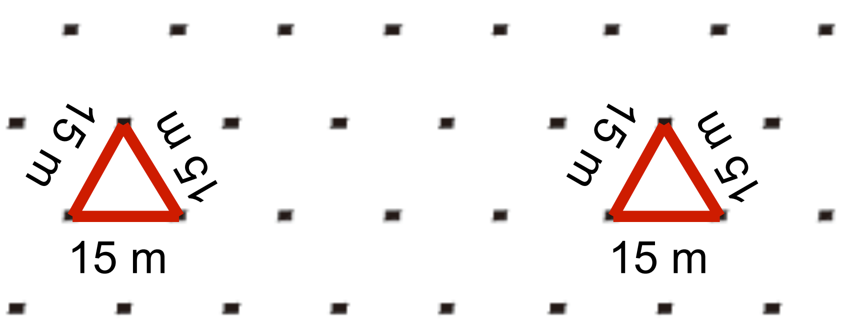


Item	Value
Cell area	25 m^2
Effective water depth	4 m
Water transparency	> 15 m (400 nm)
Precision of time measurement	0.5 ns
Dynamic range	1-4000 PEs
Time resolution	<2 ns
Charge resolution	40% @ 1 PE 5% @ 4000 PEs
Accuracy of charge calibration	<2%
Accuracy of time calibration	<0.2 ns
Total area	90,000 m^2
Total cells	3600

Electromagnetic particle Detector

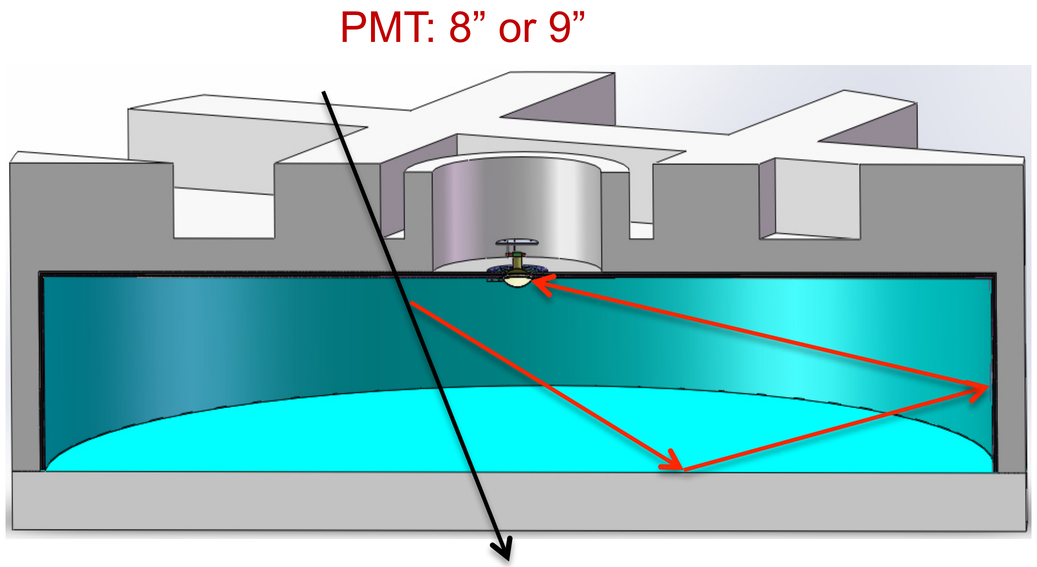


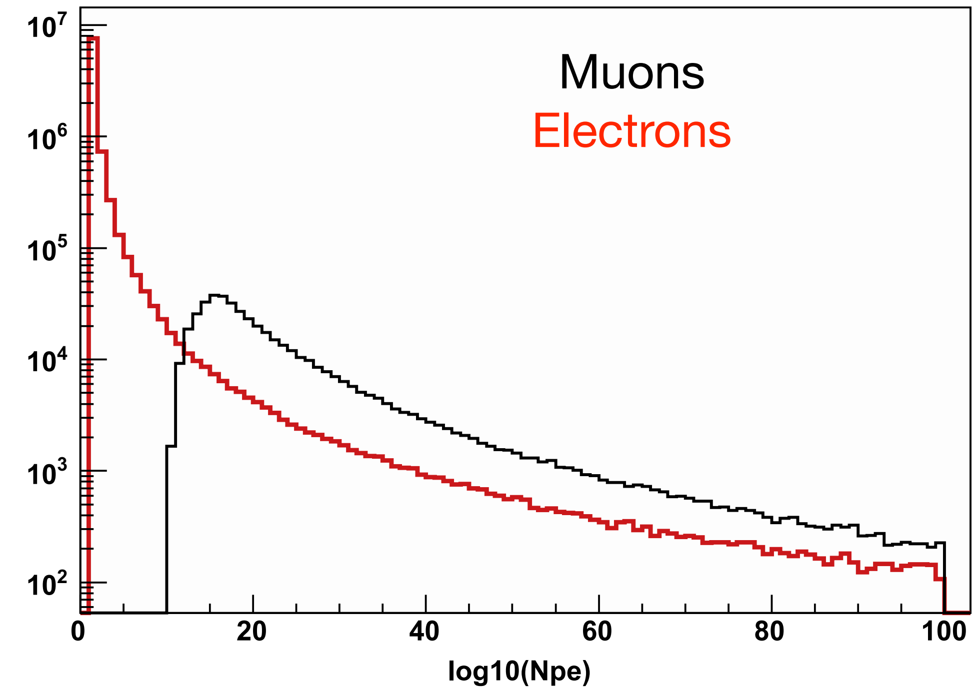




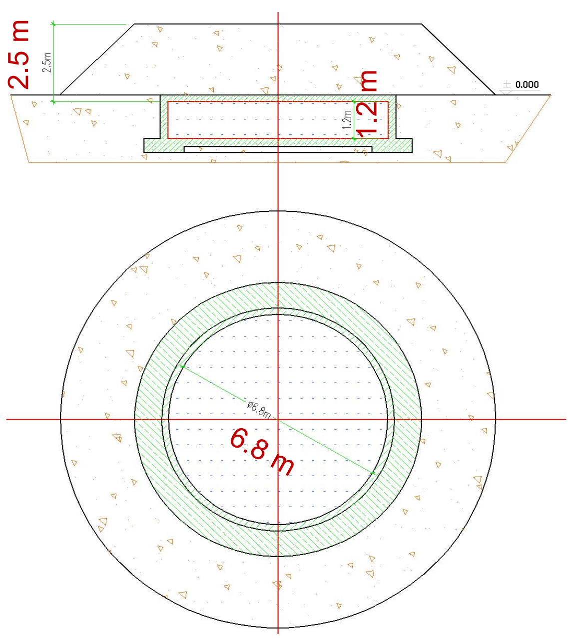
Item	Value
Effective area	1 m^2
Thickness of tiles	2 cm
Number of WLS fibers	8/tile×16 tile
Detection efficiency (> 5 MeV)	>95%
Dynamic range	1-10,000 particles
Time resolution	<2 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging	>10 years
Spacing	15 m
Total number of detectors	5635

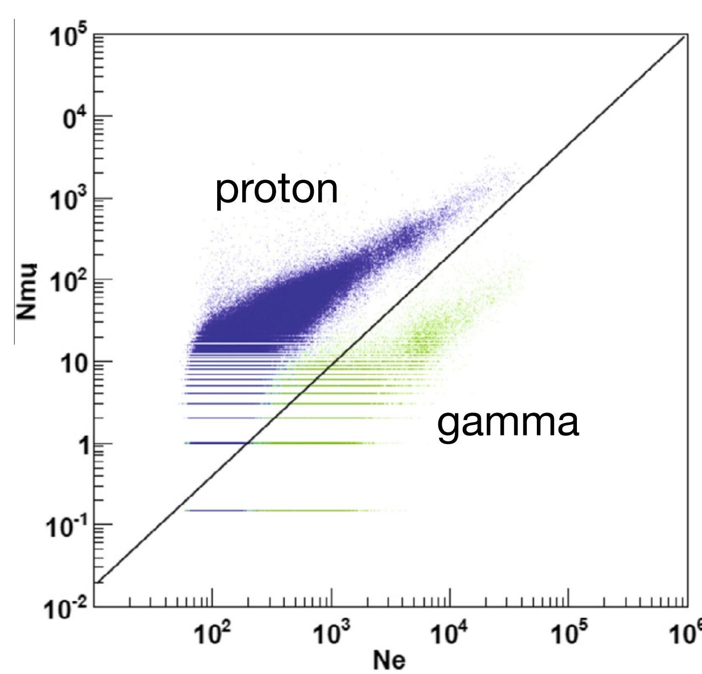
Muon Detector





Photoelectrons distribution at R > 100 m from the shower core position



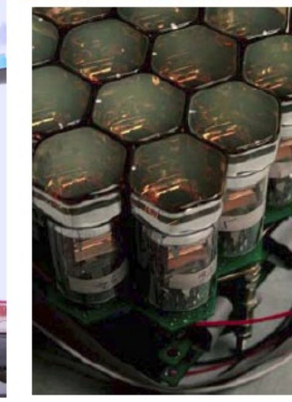


Item	Value
Area	36 m^2
Depth	1.2 m
Molasses overburden	2.5 m
Water transparency (att. len.)	> 30 m (400 nm)
Reflection coefficient	>95%
Time resolution	<10 ns
Particle counting resolution	25% @ 1 particle 5% @ 10,000 particles
Aging	>10 years
Spacing	30 m
Total number of detectors	1221

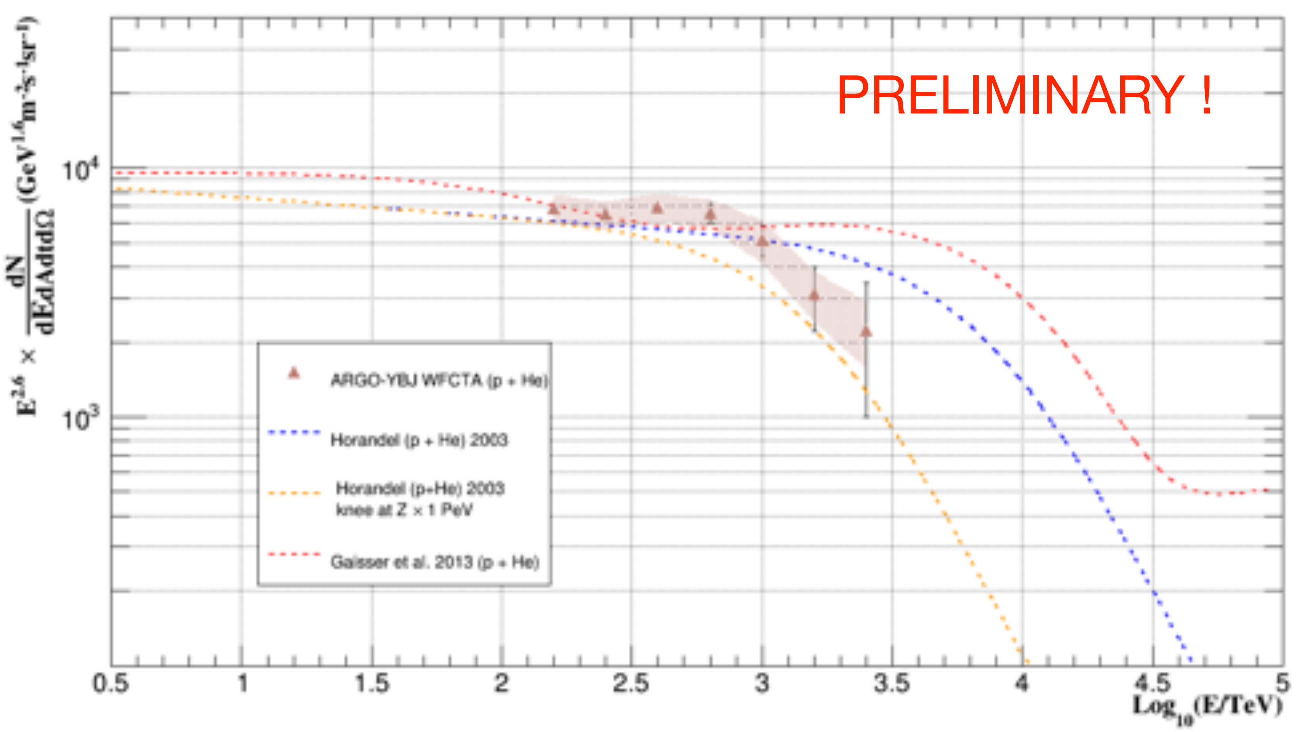
Wide field of view Cherenkov Telescope Array

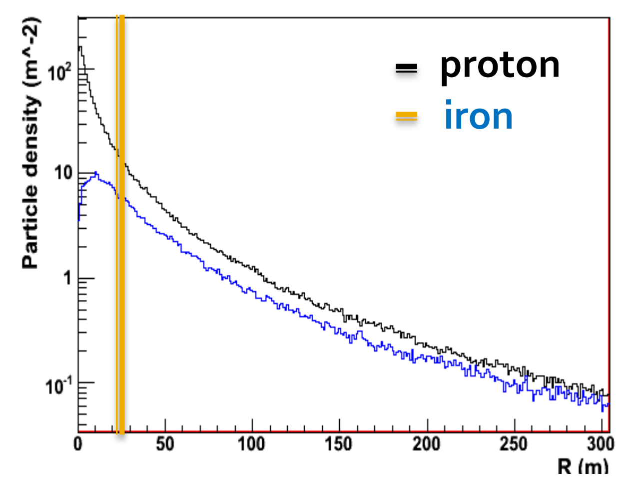
24 telescopes (Cherenkov/Fluorescence)

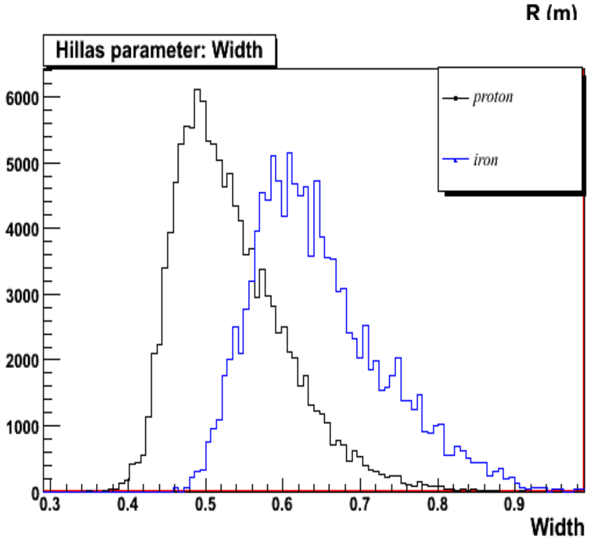
- 5 m^2 spherical mirror
- 16 × 16 PMT array
- pixel size 1°
- FOV: 14° × 14°
- Elevation angle: 60°

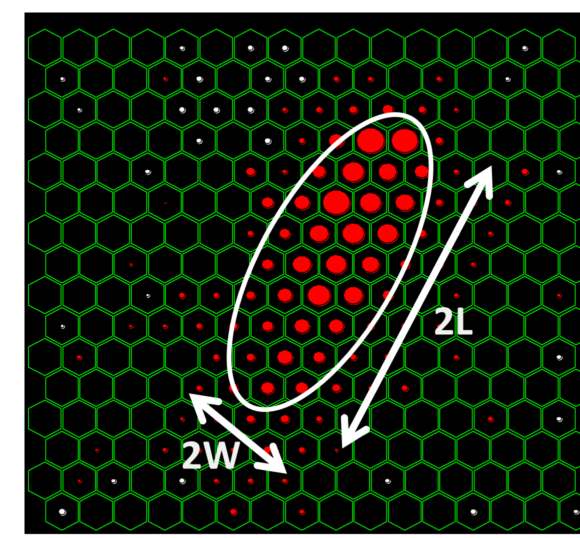


ARGO-YBJ / WFCTA

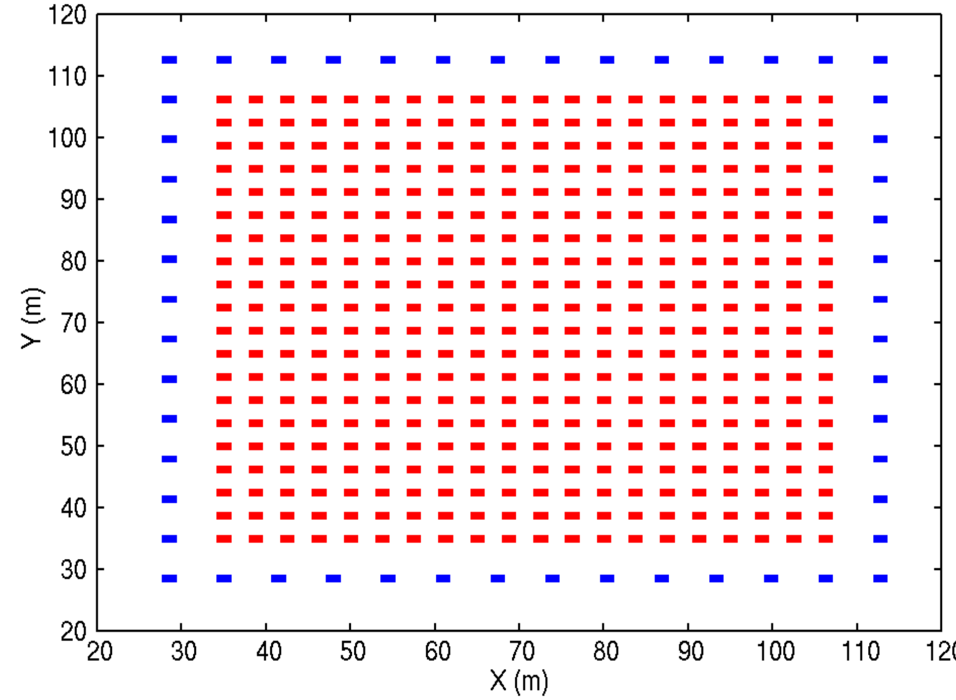






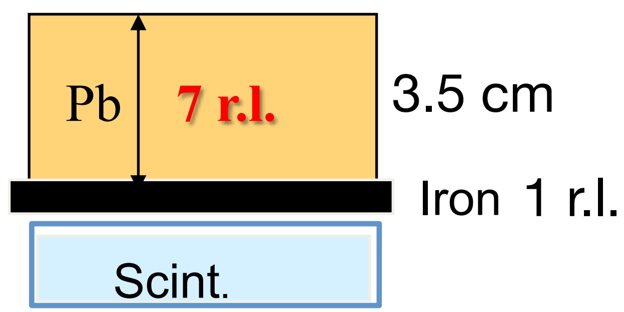


Shower Core Detector Array



- 425 close-packed burst detectors, located near the centre of the array, for the detection of high energy secondary particles in the shower core region.

Burst Detector

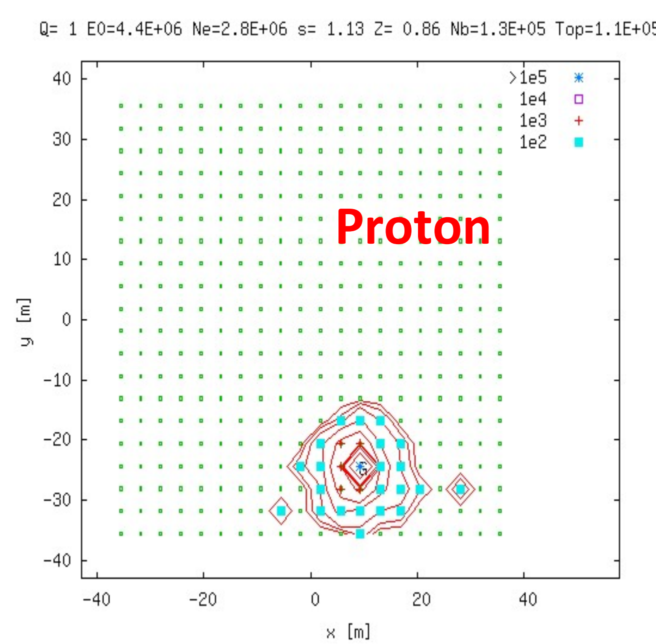


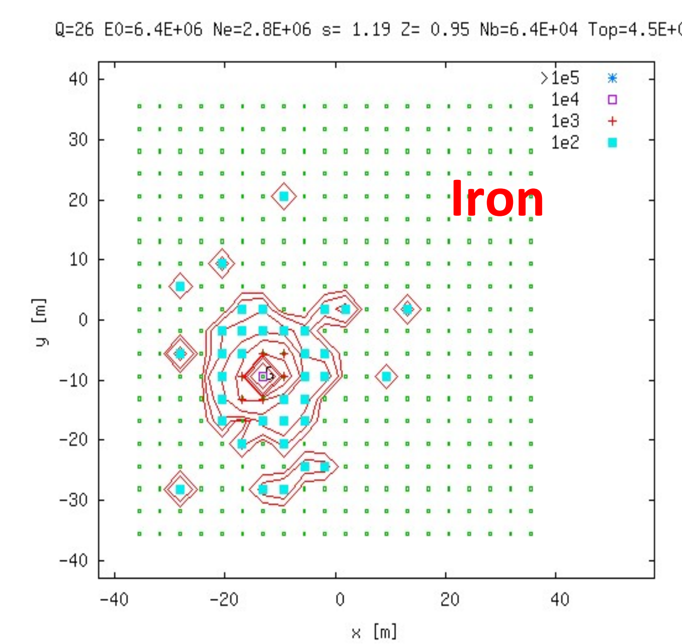
The burst detectors observe the electron size (burst size) under the lead plate induced by high energy e.m. particle in the shower core region

- Number of SCD: 0.5 m^2 x 452
- Cover Area: 5170 m^2
- Energy region: 30 TeV - 10 PeV
- Core position resolution: 1.5 m @50 TeV

Each burst detector is constituted by 20 optically separated scintillator strips of 1.5 cm × 4 cm × 50 cm read out by two PMTs operated with different gains to achieve a wide dynamic range (1- 10^6 MIPs).

- Lead plate (80 cm X 50 cm X 7 rl)
- Iron plate (1 m X 1 m X 1 rl)





The LHAASO site

The experiment will be located at 4300 m asl (606 g/cm^2) in the Daocheng site, Sichuan province, China.

Coordinates: 29° 21' 31'', 100° 08' 15''

Status of LHAASO

- LHAASO is one of the '*Five top priorities*' projects of the Strategic Plan of IHEP approved by the Chinese Academy of Sciences (CAS).

- The National Reform and Development Commission (NRDC) and the Finance Ministry (FM) allocated for LHAASO 1 Billion CNY (about 160 M US$) ➜ *“Flagship Project”*.

- The government of Sichuan province will cover the total cost of the infrastructure construction: 300 M CNY.

Tentative Schedule (Sept. 2014)

★ May, 2015: approval of the environment impact evaluation.
★ Oct, 2015: start of construction of first quarter of WCDA, KM2A.
★ Aug, 2016: installation of PMTs of WCDA.

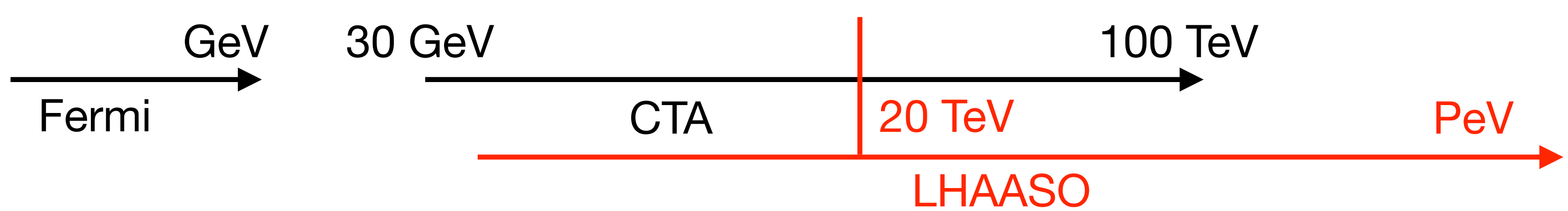
★ Spring, 2017: start scientific operation of the first quarter of LHAASO.

★ 2019: conclusion of installations.

Why LHAASO ?

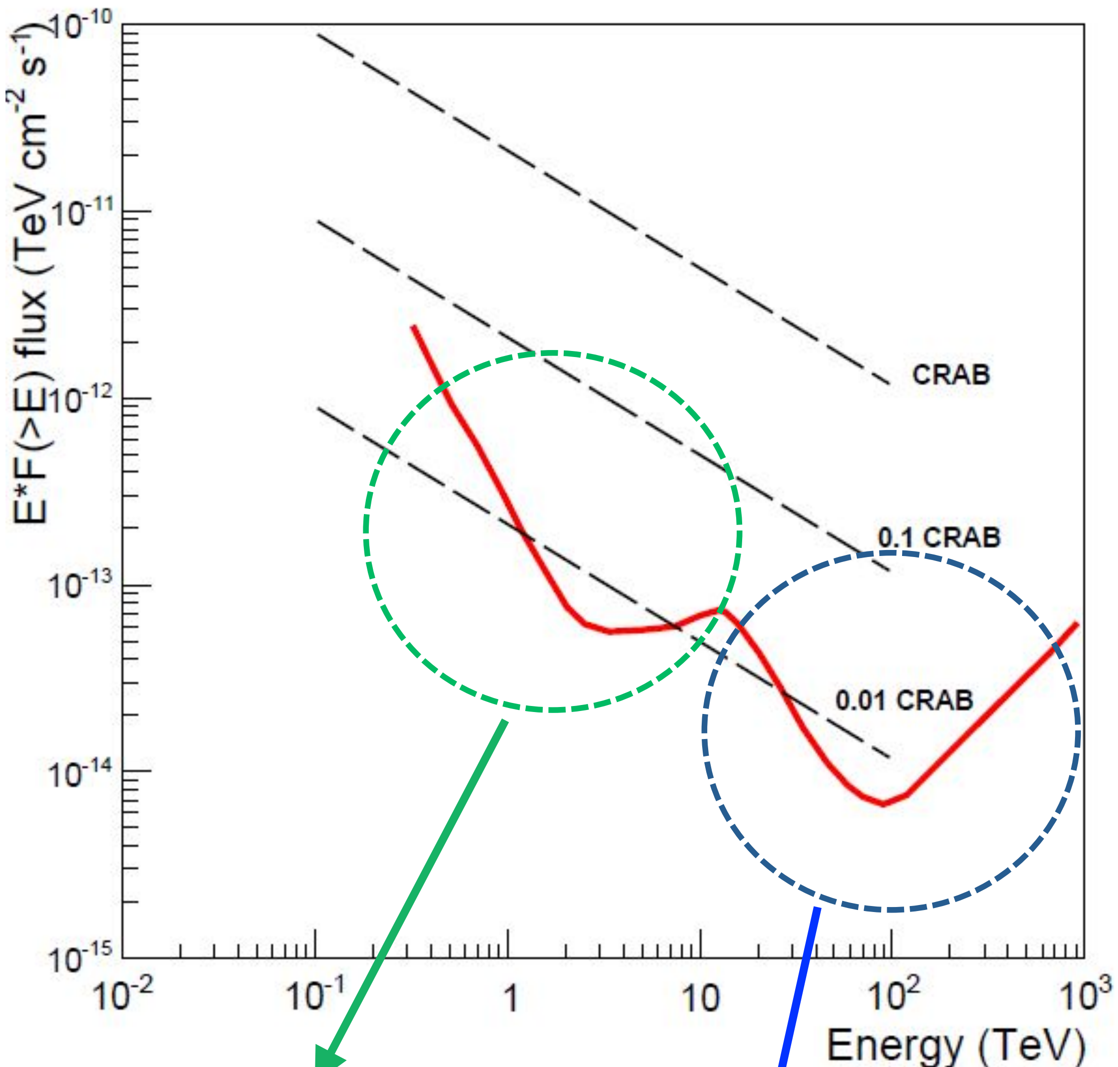
The LHAASO experiment will be the next generation ground-based experiment, capable of acting simultaneously as a Gamma Ray Telescope and a Cosmic Ray Detector.

- **Gamma-Ray Astronomy ($10^2 \rightarrow 10^6$ GeV):** full sky continuous monitoring
  - *Below 20 TeV*: continuous monitoring of the Northern sky at < 0.01 of the Crab flux
    → Sky survey: complementarity with CTA (Cherenkov Telescope Array)
  - *Above 20 TeV*: continuous monitoring of the Northern sky up to PeV with a sensitivity 2000x CTA for sky survey > 70 TeV→ search for PeV cosmic ray sources (*Pevatrons)*



- **Cosmic Ray Physics ($10^{12} \rightarrow 10^{17}$ eV):** precluded to Cherenkov Telescopes
  - CR energy spectrum
  - Elemental composition
  - Anisotropy

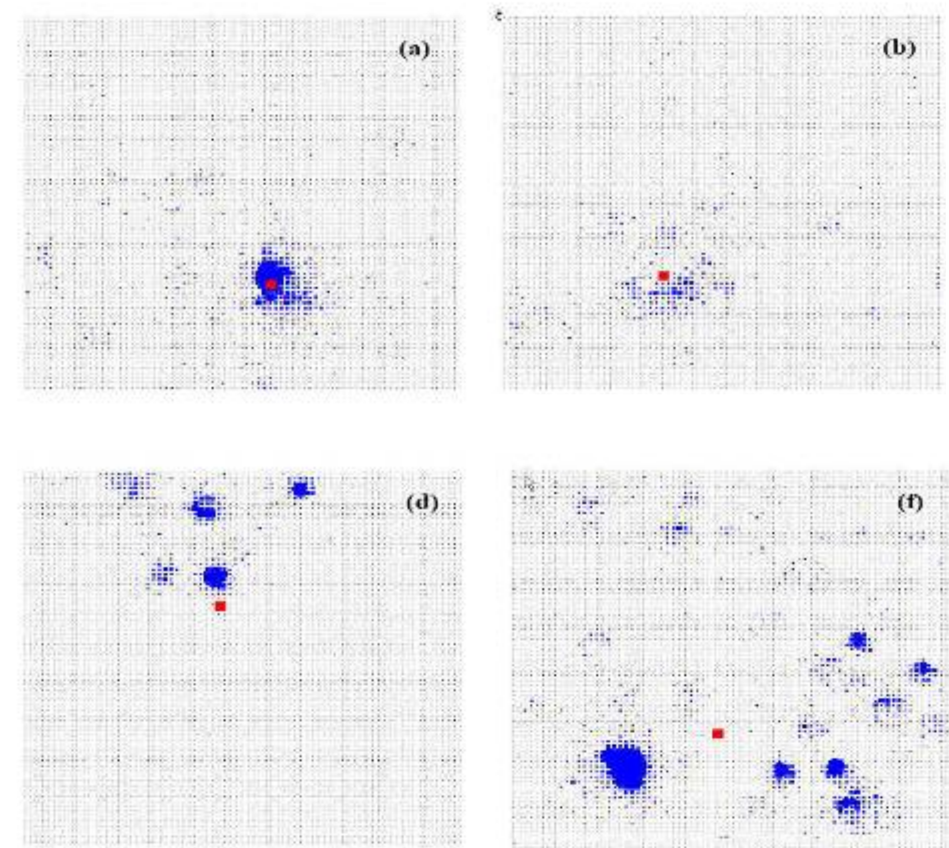
LHAASO integral sensitivity for Crab-like sources



WCDA discrimination

gamma

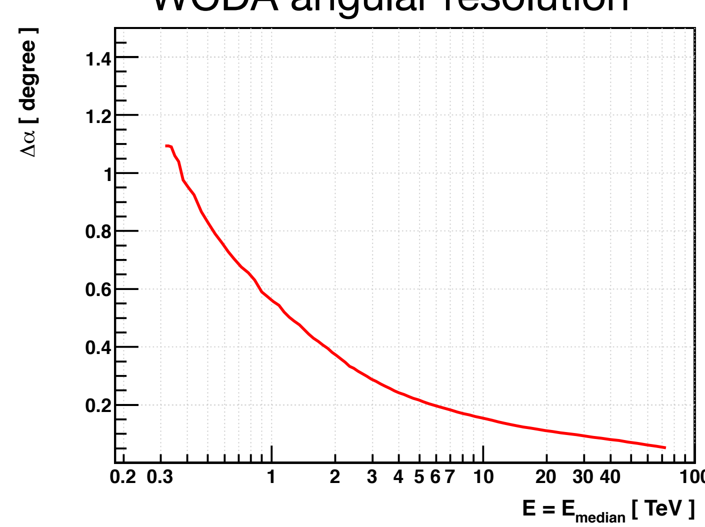
proton



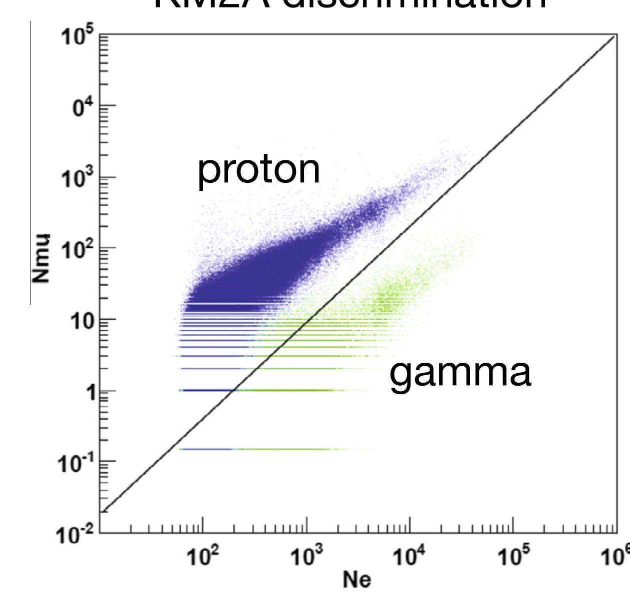
WCDA

1 KM2A (EDs + MDs)

WCDA angular resolution



KM2A discrimination



LHAASO Physics Potential

From TeVCat:

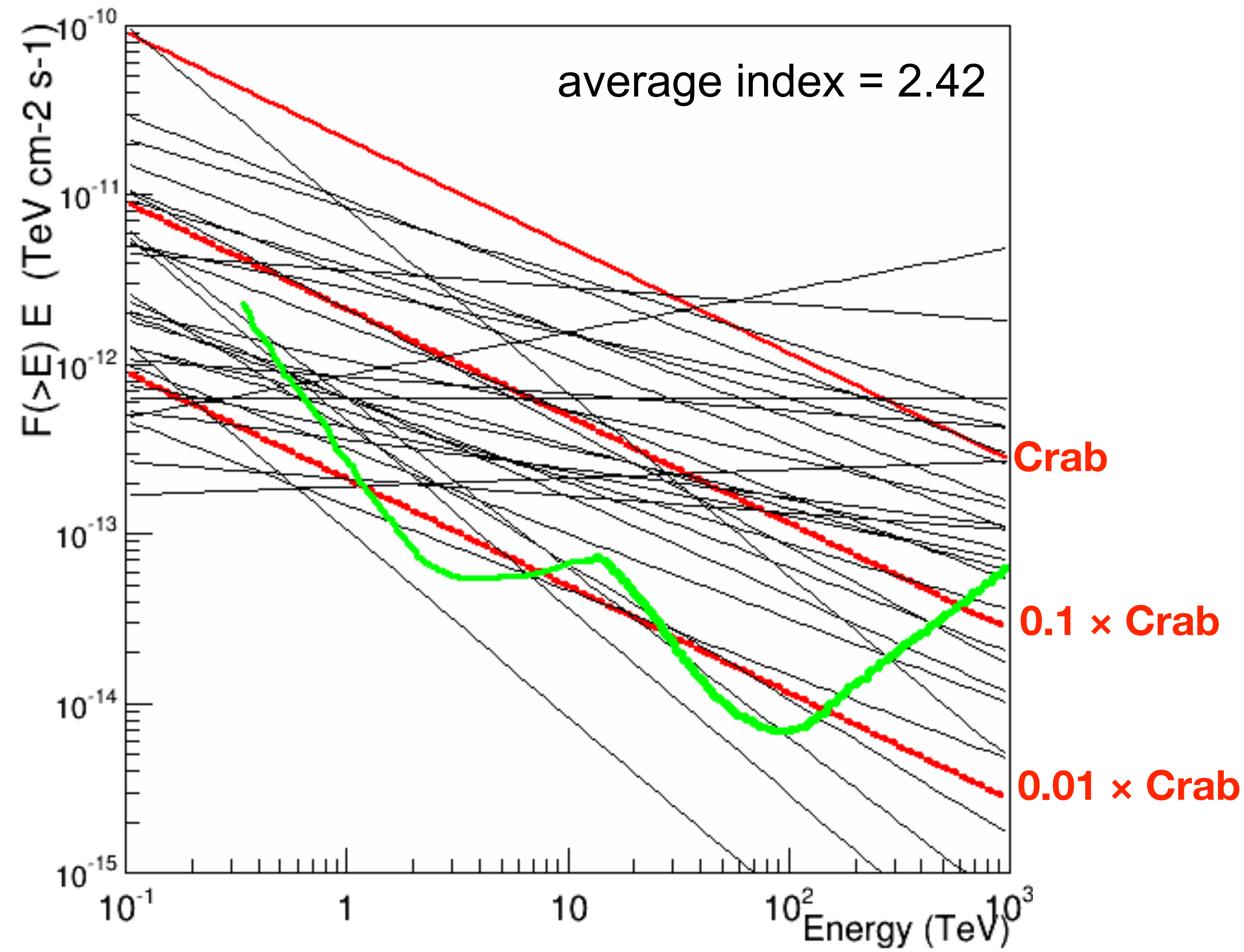
71 sources culminating at zenith angle < 40°

LHAASO latitude = *30° N*
-10° < decl < 70°

- 40 extragalactic
- 31 galactic

13	Unidentified
9	Pulsar Wind Nebulae
6	Shell Supernova Remnant
2	Binary System
1	Massive Star Cluster

Extrapolation of TeV spectra assuming no cutoff



70% of Galactic sources are extended

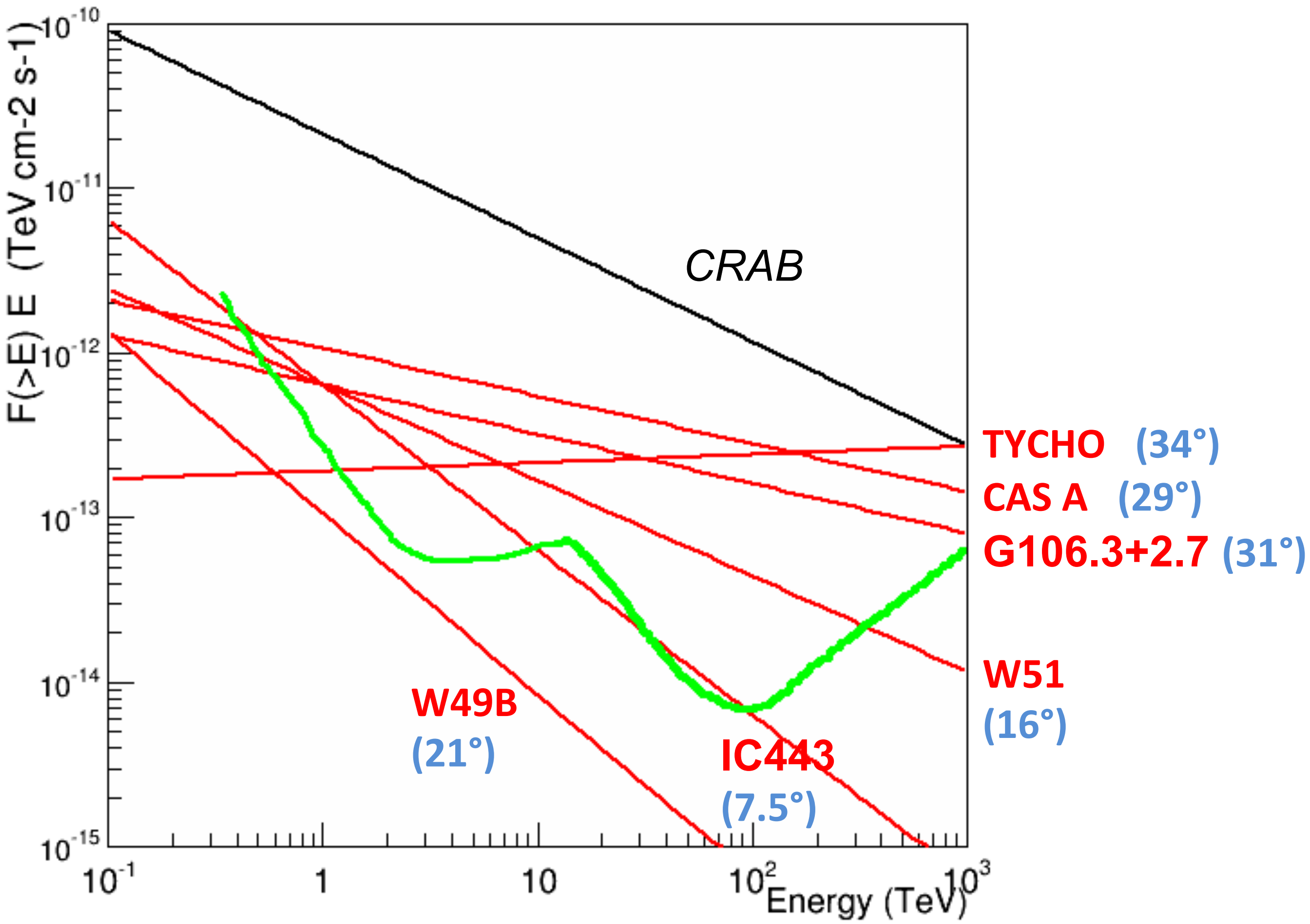
Probably the fluxes are higher then what measured by IACT

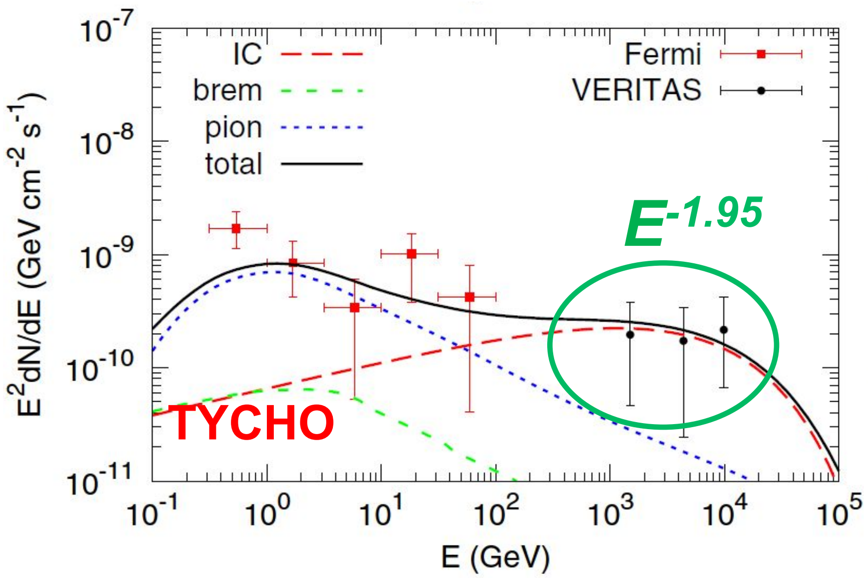
The real sensitivity depends on spectral slope, culmination angle and angular extension of the source

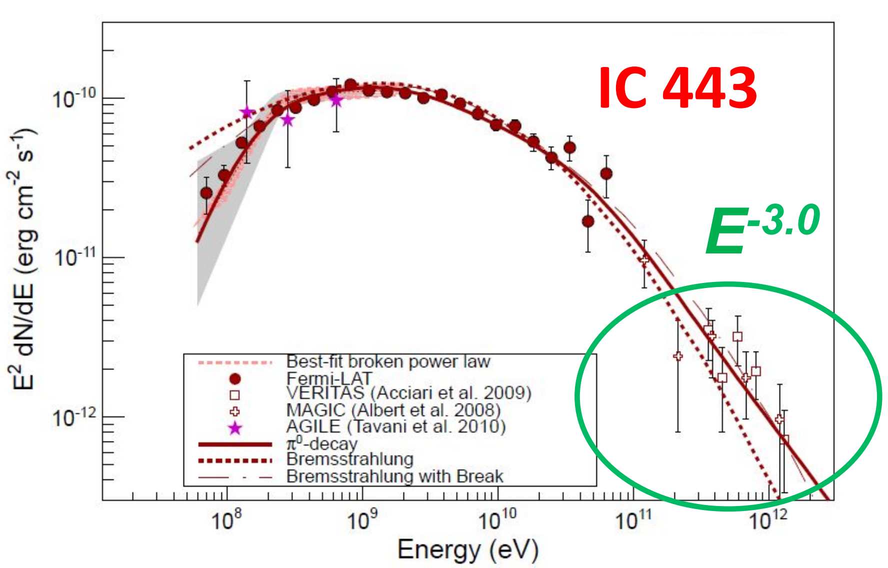
6 Shell SuperNova Remnants

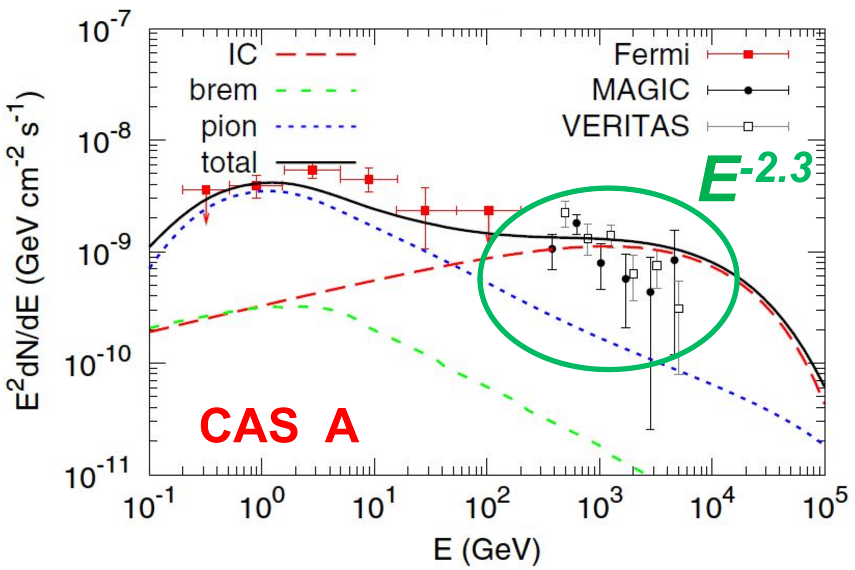
Source	Zenith angle culm.	F > 1 TeV (c.u.)	Energy range	Spectral index	Angular Extension (σ)
Thyco	34°	0.009	1-10	1.95	
G106.3+2.7	31°	0.03	1-20	2.29	0.3° x 0.2°
Cas A	29°	0.05	0.5-10	2.3	
W51	16°	0.03	0.1-5	2.58	0.12°
IC443	7.5°	0.03	0.1-2	3.0	0.16°
W49B	21°	0.005	0.3-10	3.1	

No cutoff observed in the 6 TeV spectra

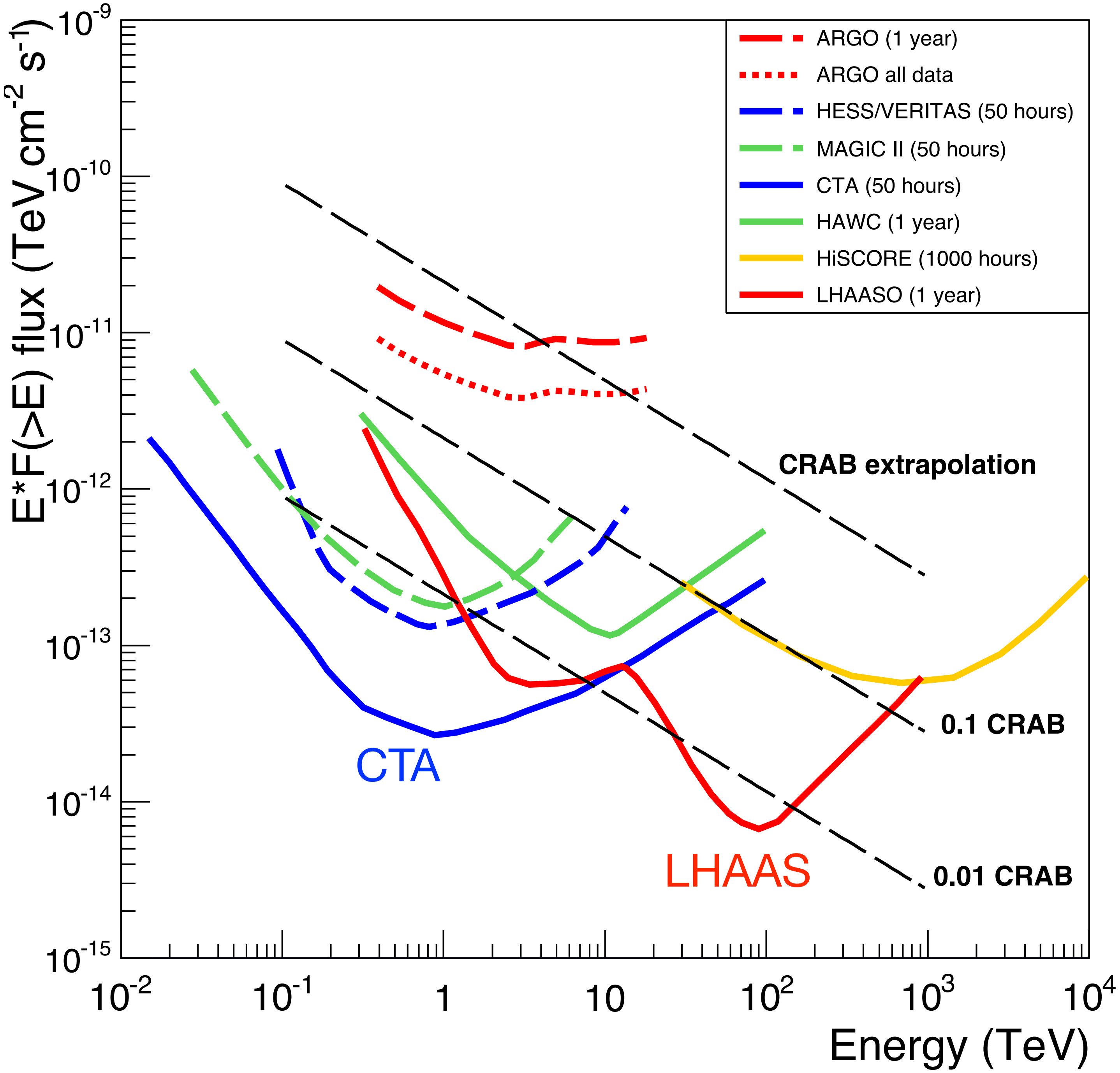








LHAASO sensitivity to gamma point sources



EAS-array: 5 s.d. in 1 year

Cherenkov: 5 s.d. in 50 h *on source*

★ 1 year for EAS arrays means:

(5 h $\times$ 365 d) ~1500 - 2200 of observation hours for each source (about 4-6 hours per day).

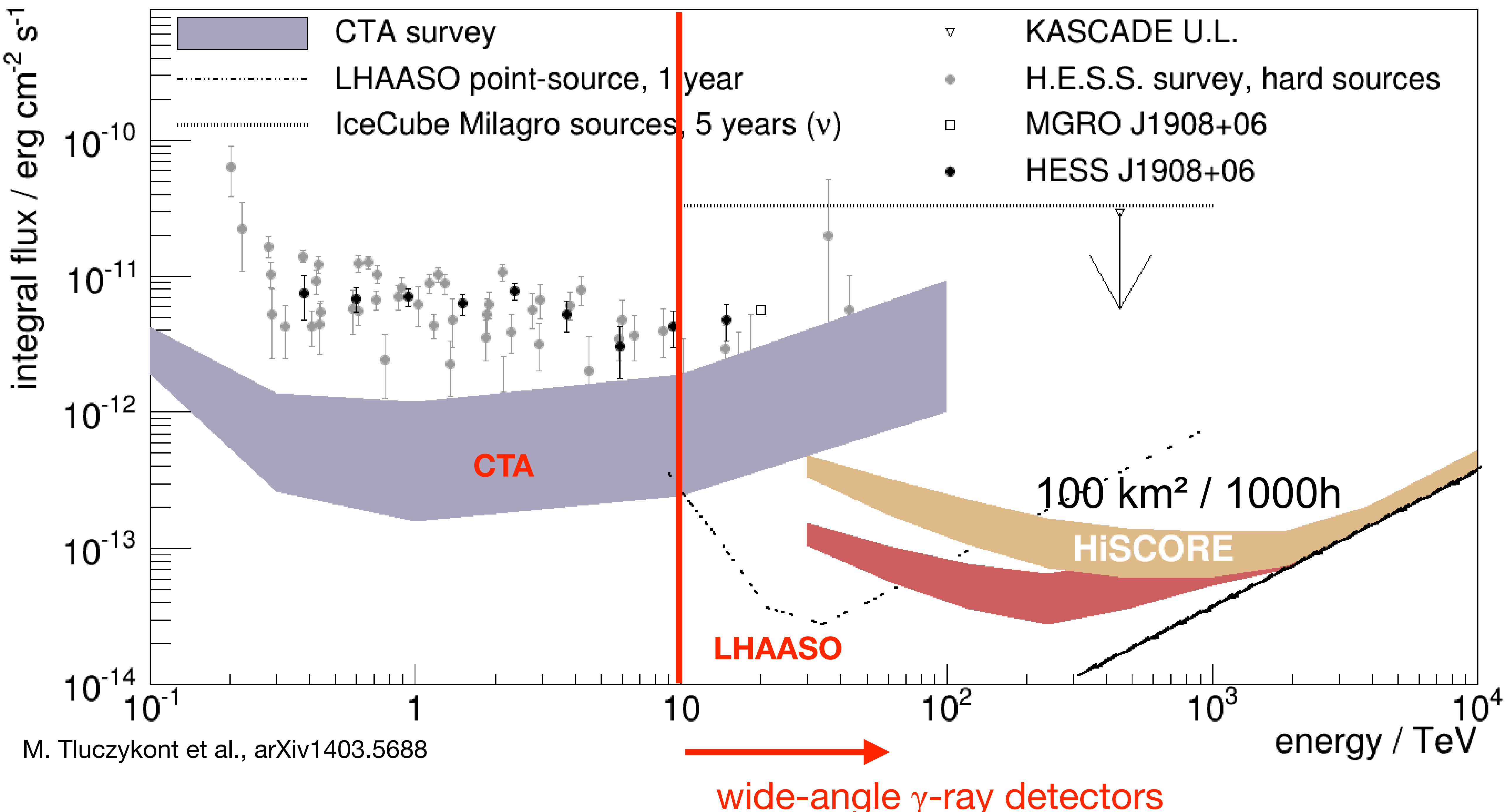
★ For Cherenkov:

(5 h $\times$ 365 d) $\times$ d.c. ($\approx$ 15%) $\approx$ 270 h / y for each source.

The big advantage of LHAASO is in sky survey !

Opening the PeVatron range

Lhaaso has no competitors for sky survey: in one year it can survey the Northen sky at 100 TeV at a level < 0.01 Crab !

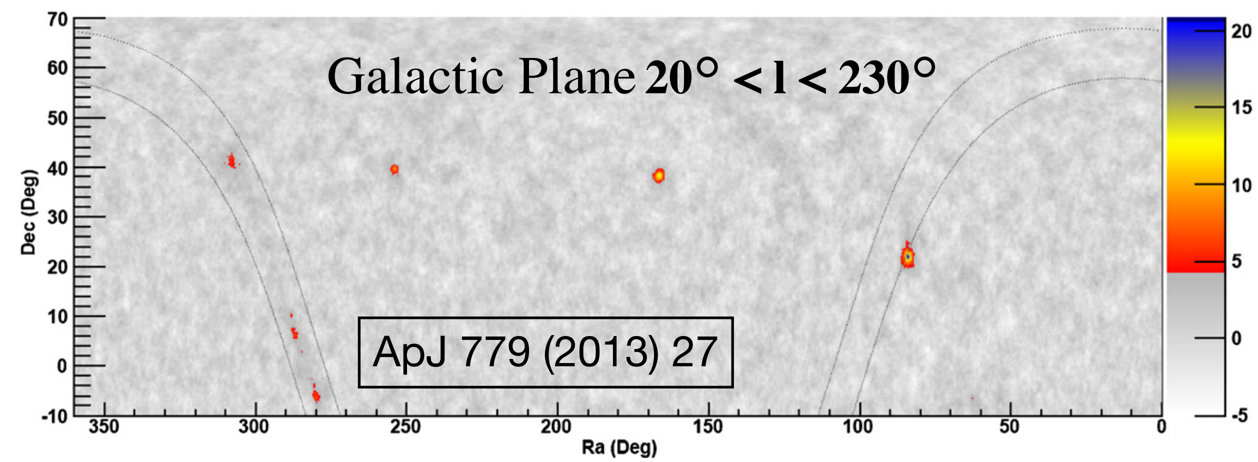


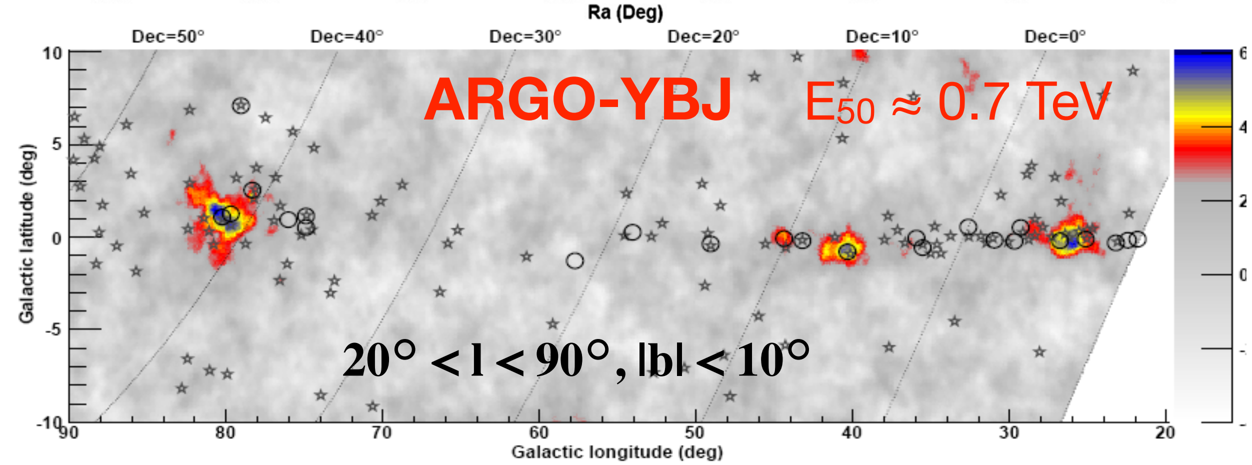
M. Tluczykont et al., arXiv1403.5688

The strong case for all sky survey instruments

The all-sky survey provides un *unbiased map of the sky* useful to

- enable the detection of unexpected sources
- provides testing ground for new theoretical ideas
- provides targets for in-depth observations





A full exploration of the Galactic Plane requires both Northern and Southern detectors !

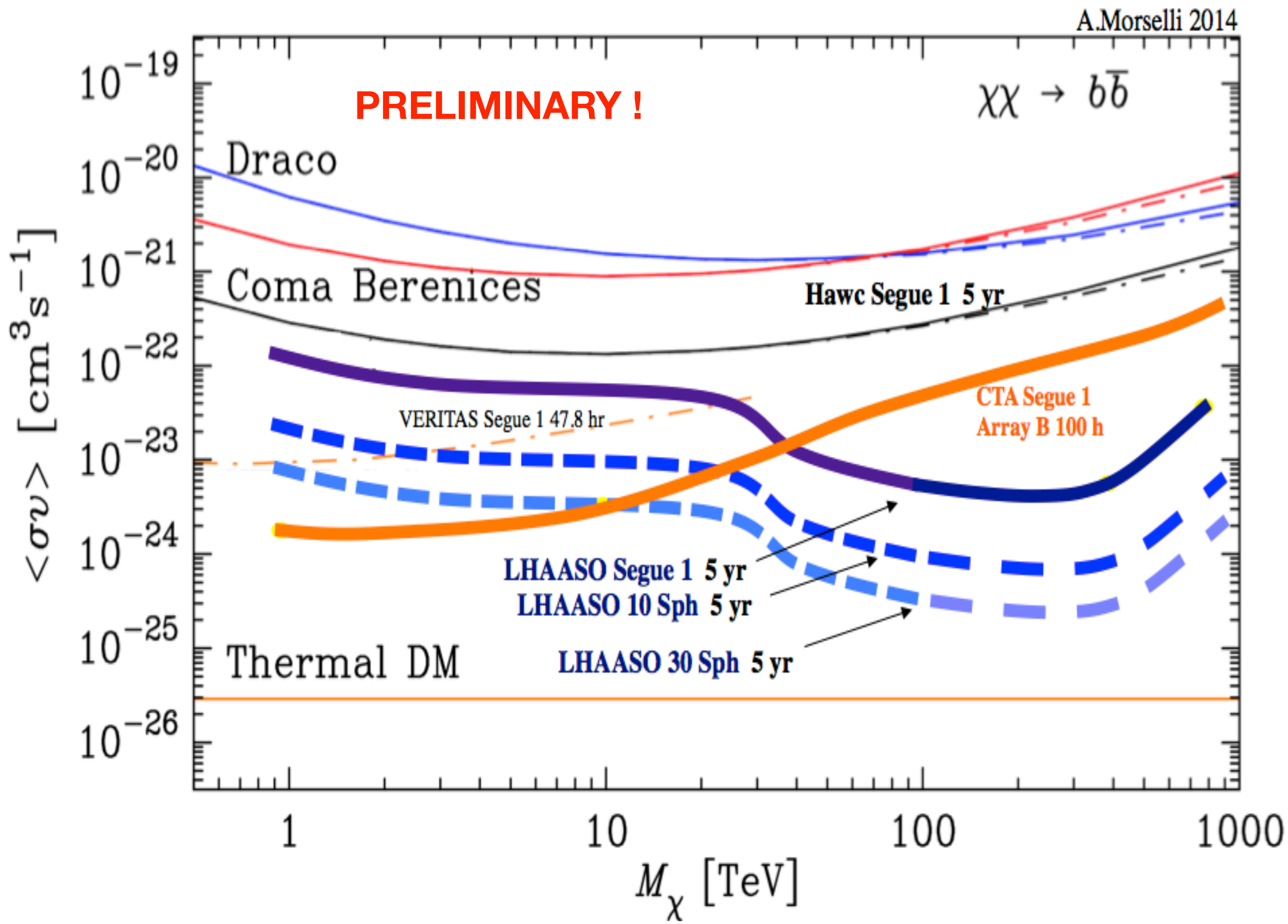
- study of flaring phenomena (GRBs, solar flares, AGNs)
- probe of diffuse emission on scales of several degrees
- study of localized CR anisotropies
- search for small and nearby high latitude molecular clouds
- constraints on Dark Matter at multi-TeV scale by *'stacked analysis'*
- blind search for annihilation in Dark Matter subhalos of the Galaxy, without any *a priori* association with an astrophysical object (dwarf galaxy, Galactic Center, etc)
- search for new, unexpected classes of VHE sources ('*dark accelerator*') useful to constrain the density in the Galactic halo of *cloudlets:* cold and dense clumps of material that may constitute a sizeble fraction of *baryonic matter* mostly invisible but not for their gamma-ray emission for CR interaction

DM search with LHAASO, CTA and HAWC

Caveat:

- 30 dSphs (3x) (supposing the observation of new dSphs)
- -10% from spatial extension (source extension increases the signal region at high energy)

LHAASO advantage: combined analysis of different dwarf galaxies observed at the same time



- There are many assumptions in this prediction
- Doesn't deal with a possible detections

update of arXiv:1405.1730, arXiv:1208.5356

Conclusions

Open problems in galactic cosmic ray physics push the construction of new generation EAS arrays in the 10^{11} - 10^{18} eV energy range.

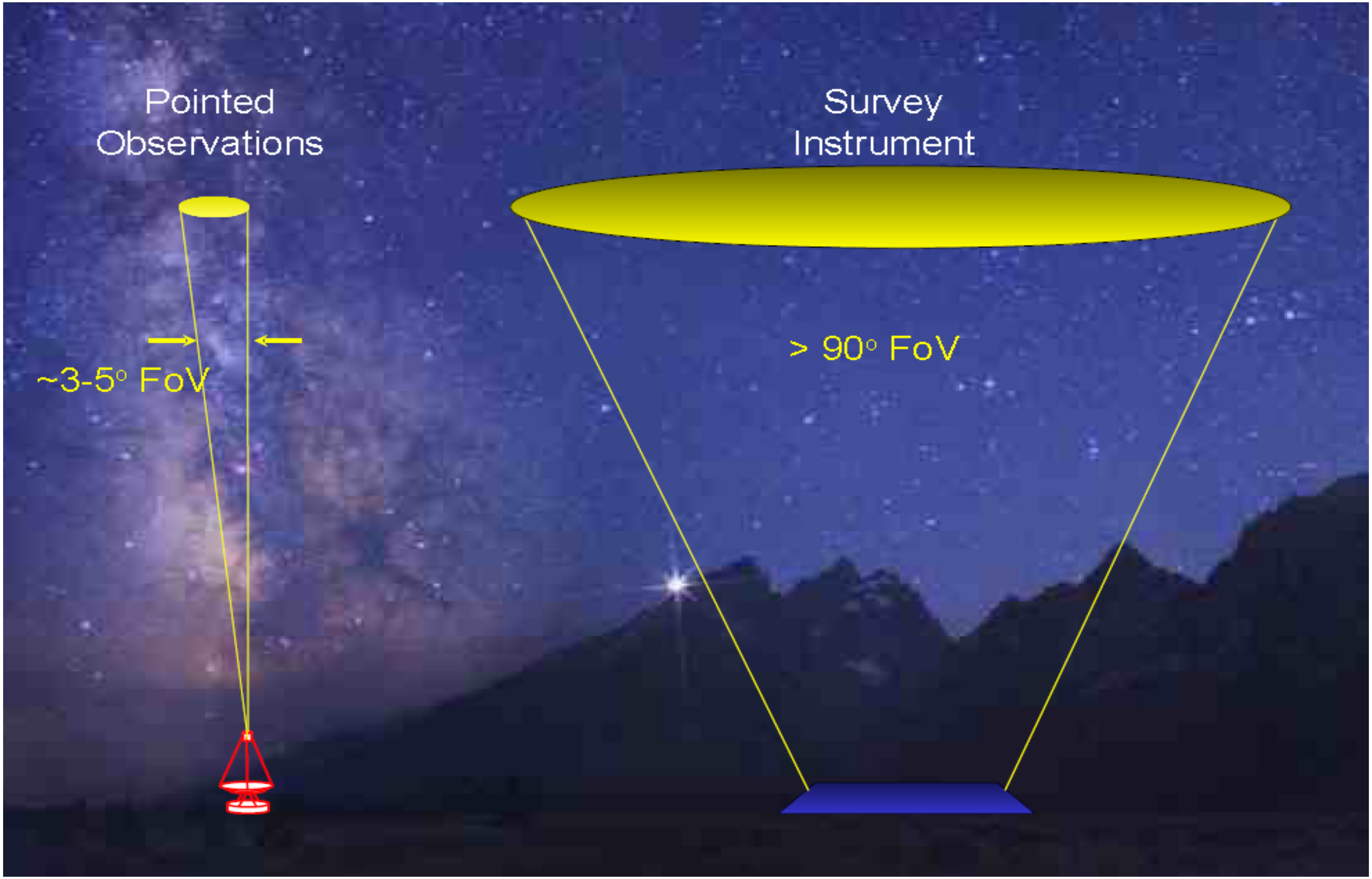
LHAASO is the most ambitious project with very interesting prospects, being able to deal with all the main open problems of cosmic ray physics at the same time.

It is proposed to study cosmic rays in a wide energy range, from those observable in space with AMS and approaching those investigated by AUGER, thus including, in addition to the 'knee', the whole region between 'knee' and 'ankle' where the galactic/extra-galactic CR transition is expected.

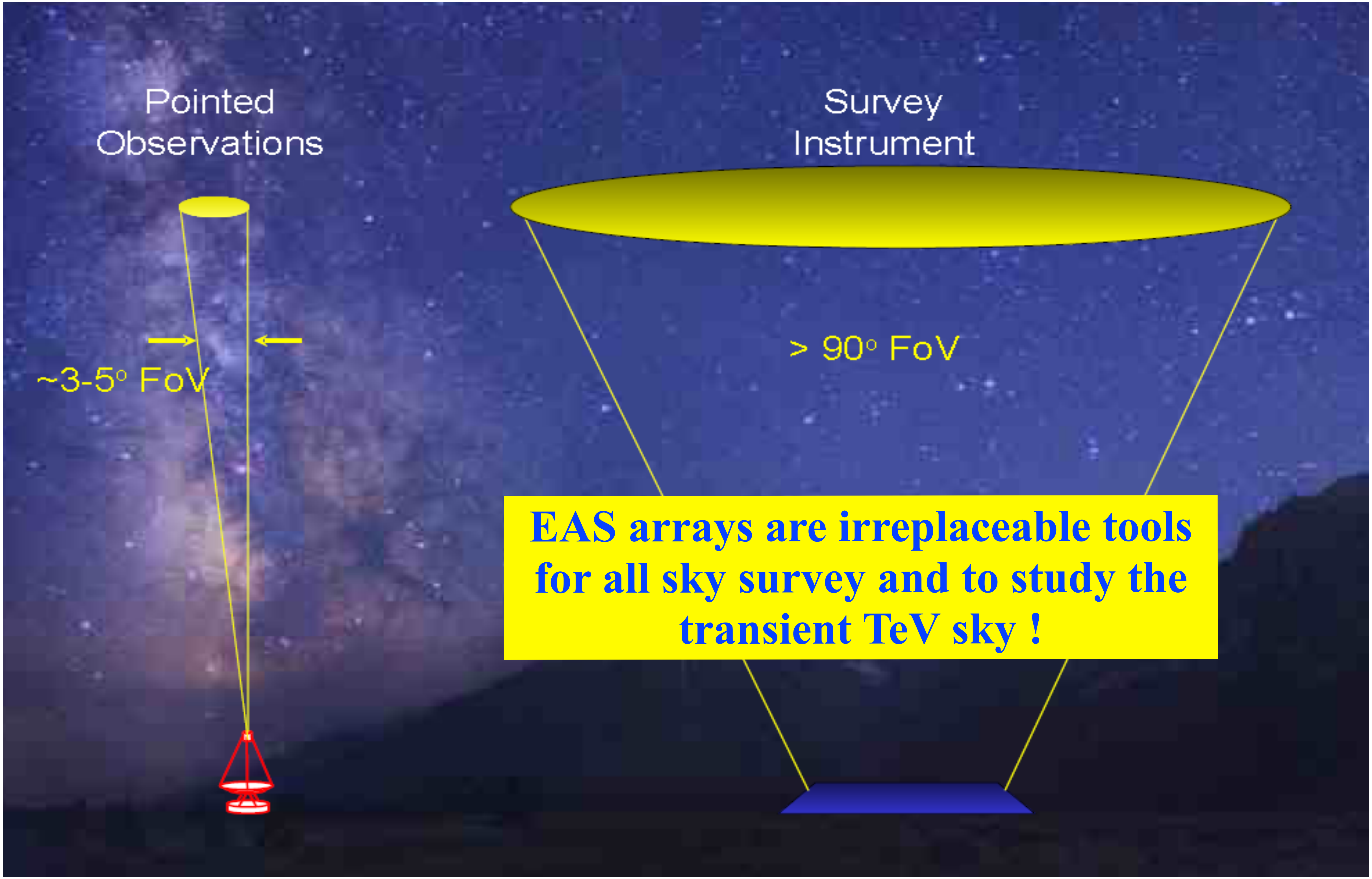
At the same time it is proposed as a tool of great sensitivity - unprecedented above 20 TeV - to monitor *'all the sky all the time'* a gamma-ray domain extremely rich of sources variable at all wavelengths.

Due to the modular structure of the experiment, first physics results are expected after only 2-3 years from the start of installation. Final installation in 5-6 years.

Pointed and Survey instruments

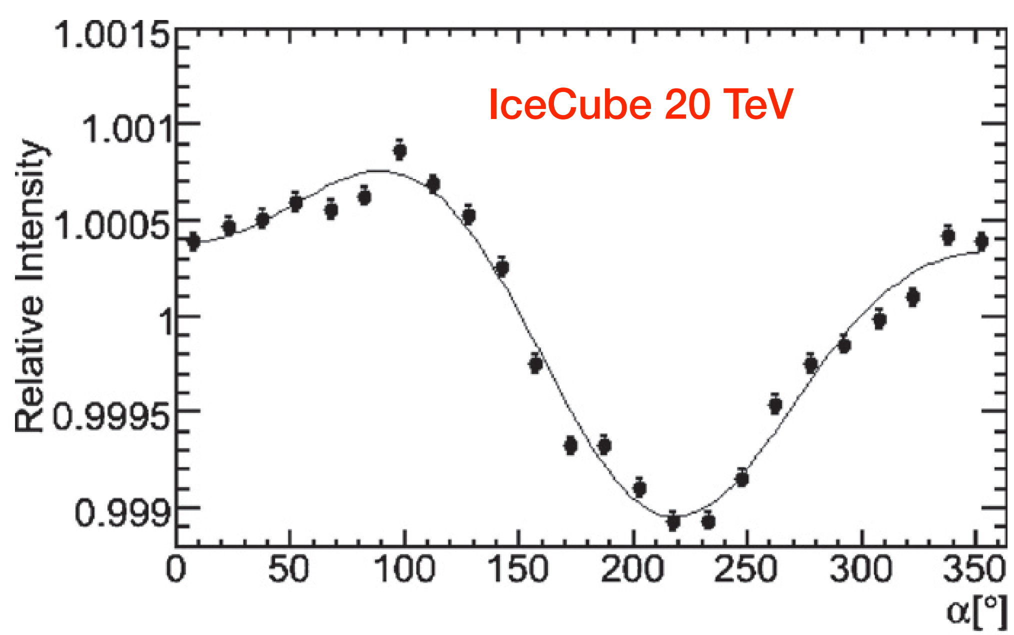


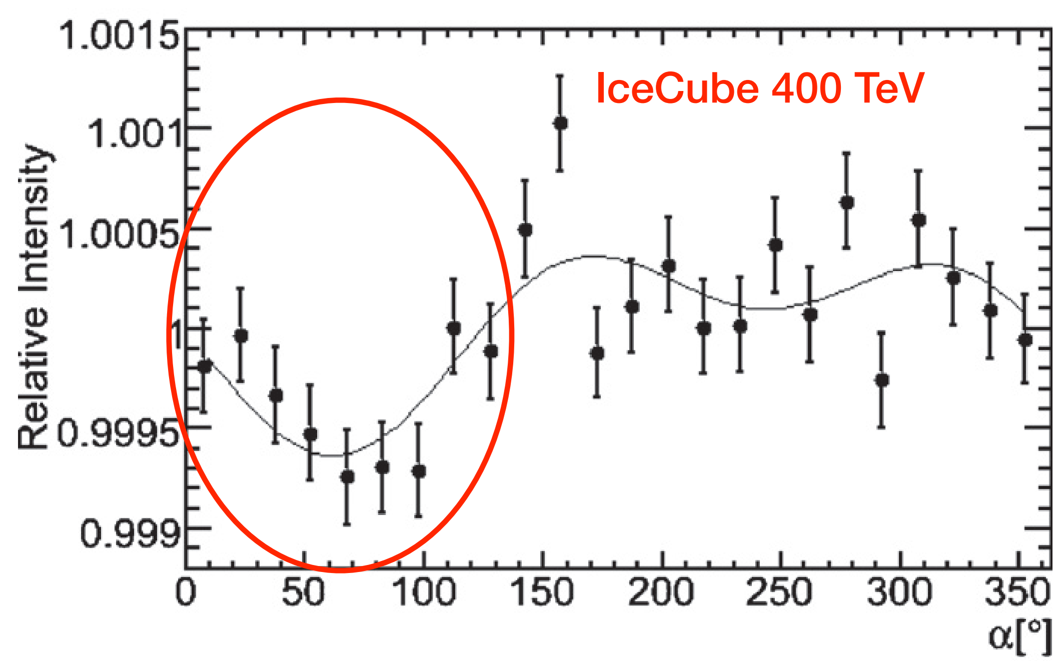
Pointed and Survey instruments



Why not a dipole ?

- Large scale anisotropy **not a dipole**, **changes topology** with energy and has **complex structure**.
- In the energy range 1 - 30 TeV, even if only a dipole + quadrupole distribution is assumed, at least 30% of the signal is due to the quadrupole (multipole of order 2).
- Reality goes much farther than the quadrupole: anisotropies down to ~10° (multipole of the order 18) were observed in the last five years in the energy range 1 - 30 TeV.
- Although statistically uncertain, above 300 TeV the R.A. projection does not reproduce a daily sine function, a localized deficit between 30° and 130° seems to be there.



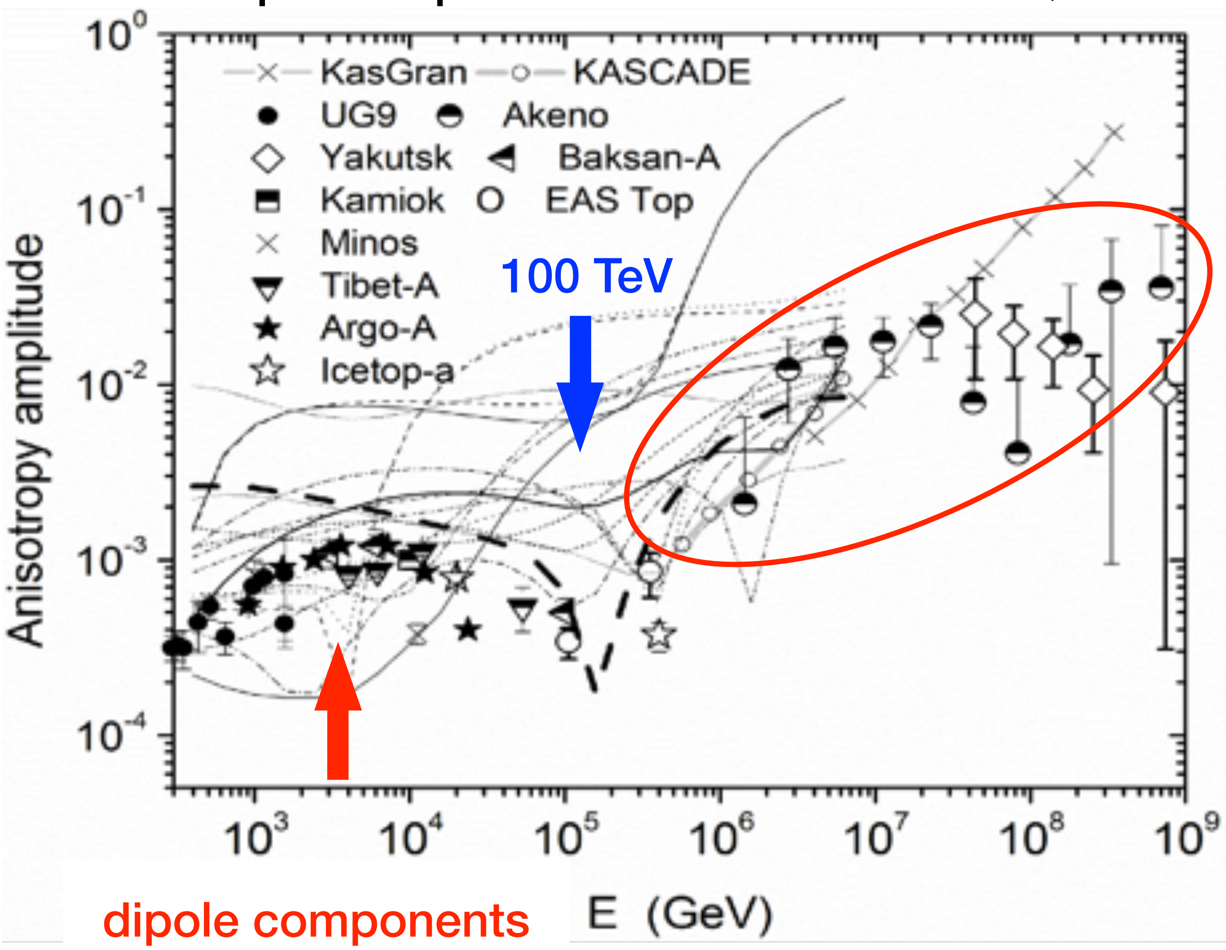


Abbasi et al, ApJ, 746 (2012) 33

LSA is NOT a dipole

Not dipole means that “amplitude” and “phase” are not well defined

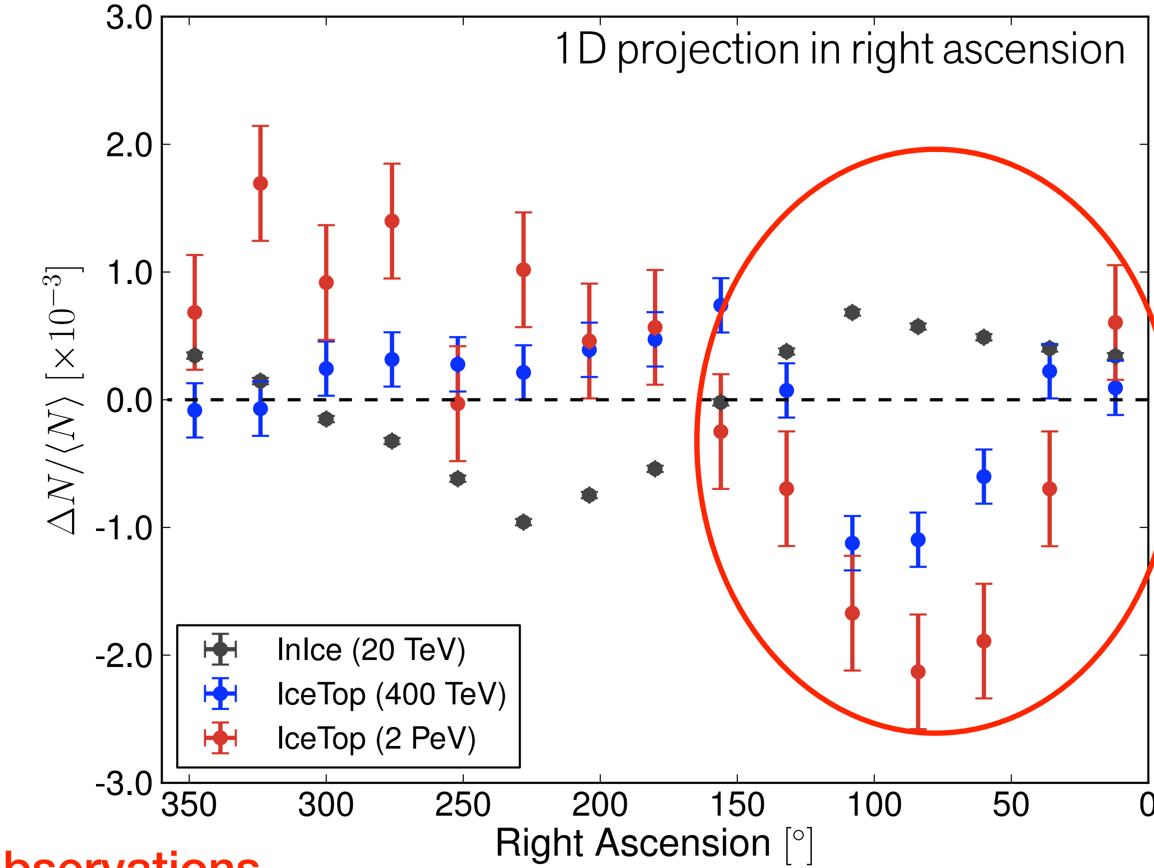
dipole amplitude Sveshnikova+, 2013



not dipole observations

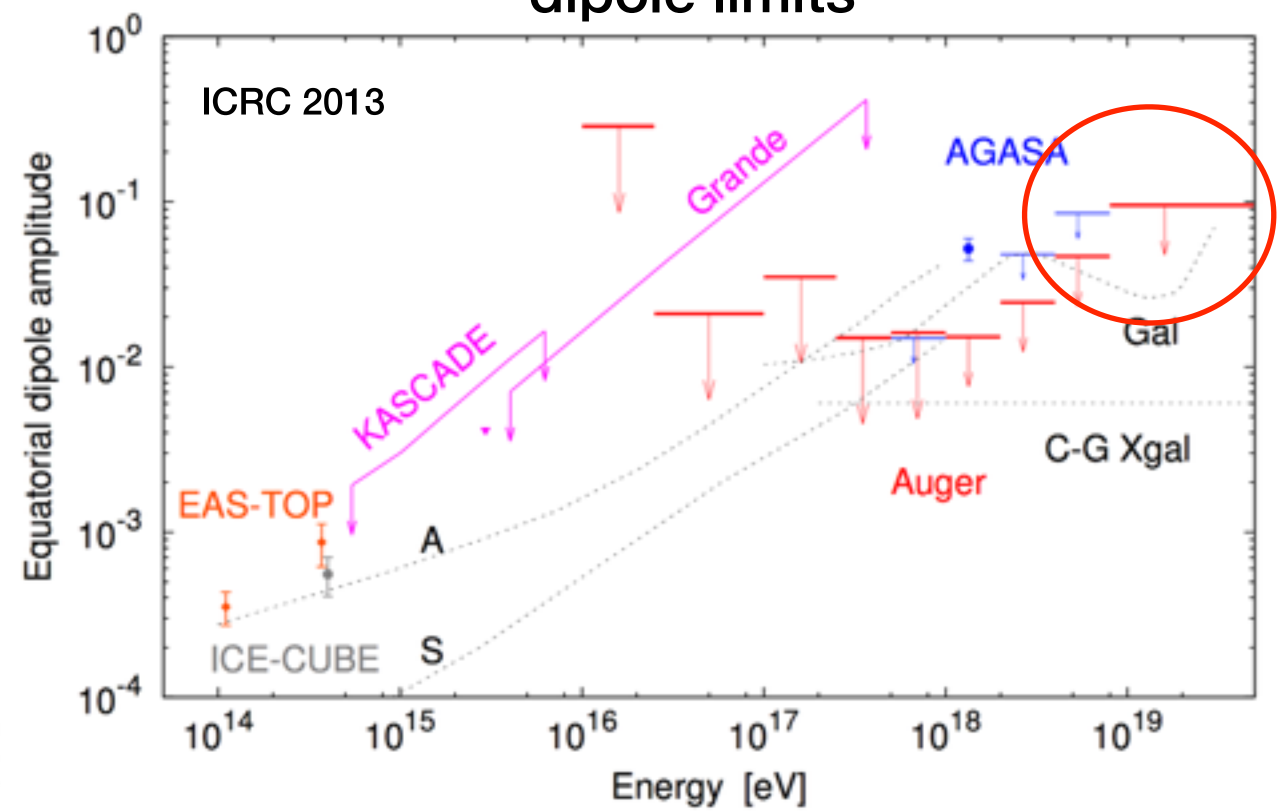
dipole components of the anisotropy

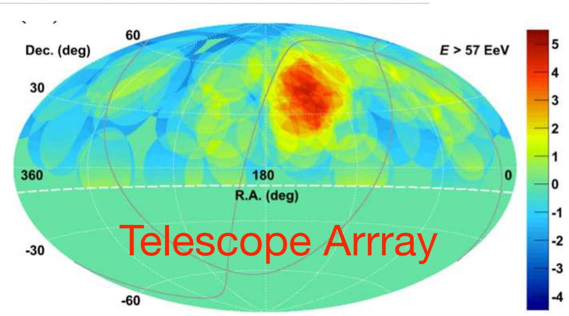
IceCube + IceTop



Aarsten et al., ApJ 765, 55 (2013)

dipole limits





Telescope Arrray

Dwarf Spheroidal galaxies (dSph)

Low luminosity galaxies that are companions to the Milky Way.
The total amount of mass inferred from the motions of stars in dSph is many times that which can be accounted for by the mass of the stars themselves ➡ this is seen as a sure sign of dark matter
Because of the extremely large amounts of dark matter in these objects, they may deserve the title *"most dark matter-dominated galaxies"*